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MODELING URBAN RIDESHARING FOR COMMUTING: HOW TO CHOOSE THE WAY YOU MOVE

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TREBALL FINAL DE GRAU

“I’ll share with the bird this lonely view”

Anthony Kiedis (Scar tissue 1999)

i. **ABSTRACT**

The present study analyzes the concepts that constitute *ridesharing* and proposes a taxonomy of its different modes depending on the ownership level of the driver and on the payment conditions. It also includes the mode of the private vehicle, in order to compare its cost with the ridesharing alternatives.

The evaluated alternatives are: shared rides for free and hitch-hiking, shared rides with payment, carpooling, carsharing, private transport networks such as Uber and conventional taxicab services.

The focus of this work is on analytical modeling for the cost of the options in an urban and metropolitan region: Barcelona, the place where the modeling will be applied. For this reason, the estimated variables and parameters are based on this region. The models have been created in order to use similar continuous variables. For this reason, it is possible to establish a grading of options depending on these variables.

The results show some analysis of the models for evaluating the most important variables. It is also introduced a comparison between modes depending on some characteristics of the trip, such as the trip length, and the number of passengers. In this way, it is possible to decide which kind of mode of ridesharing is more appropriate depending on each one necessities.

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1. INTRODUCTION AND OBJECTIVES

1.1. MOTIVATION

The cities are growing as many people has moved from the country to the city in the last years. The density of the cities has increased, creating the metropolitan areas. Due to that, the transport into and to the city has needed an improvement of the road and streets characteristics, as far as building new of them and new transport networks as metro lines as well. However, we have reach a situation where not everything consists on improve and expand our infrastructures —as they have already been modified and built during years—but consist on optimizing the way we move along them. It means we should start considering new cost-efficient modes of transport, such as ridesharing.

The motivation for this work grew up during these last years commuting to the university and to work. In the rush hours, it is very easy to notice how a car, which is a machine invented for travelling at 120 km/h or more, is moving even slower than a bicycle. This is happening not only into the city streets but also in the surrounding areas and highways.

What is the problem? There are lots of them. However, one of the principal problems is very easy to realize when you look into the cars passing along some road or street: you will only perceive cars with one single occupier!

This mobility attitude is not only making lower our quality of life because of stress, density of vehicles on the street, waste of time, parking problems, or noises for example, but also due to the air pollution. This is a huge actual problem which doesn't affect only the city inhabitants or characteristics, also it affects the global environmental change so affects the full world, it means people and even animals who live thousands of kilometers away from the city.

Humans have tried different solutions for the global change. Many of them are very useful but sometimes they have difficulties to be implemented, such as electrical cars. It does not means that they are not well developed because as far as I know, they can travel as fast as a normal car. It means that people is not used to this kind of vehicles yet, and as we wait for the next step of using environmentally friendly vehicles, we cannot wait with folded arms. What we have to do is start to change the point of view about the usage of our “traditional” vehicles. This will contribute to an effective mobility through the city too.

The use of the ridesharing is one of the effective solutions to the problem. The aim is to share the trip with that one who is going to the same destination, and who maybe is your neighbor. Imagine how the numbers of vehicles on the road would decrease just if people uses this concept.

The fact is that it looks easy, but why is not people doing it? Sharing economies are such a new concept, which is gaining importance as our society is changing. About twenty years ago, people did not do it a lot. Nowadays it is growing up, but still being a strange concept for lot of people. The lack of information is one of the main points: there are applications and devices that help us to know, for example, which vehicles or users would be comfortable to join with. Then people can use these tools to use more this sharing ways of living, or even to be introduced to it if they have not discovered that before.

1.2. INTRODUCTION

The increase of the population in the cities is a fact that creates problems such as congestion. Every day the commuters arrive to the cities wasting a lot of time on their vehicles. At the same

time, the air pollution also increases. One of the factors that cause the greenhouse effect is the emission of CO₂, and CO₂ is highly produced by the cars on the cities.

As far as we noticed this environmental problem, the governments, companies and researchers have invested on it, finding many solutions most of them focusing on alternative energies. This will be the final solution. Nevertheless, it should be taken into account that the change to a full environmental-friendly energy system will not be in less than 10 years. During this period, we should have other solutions that do not only change the machines or vehicles such as cars, but also the way we move with them.

This work is a study about how to compute the individual costs of ridesharing, a concept that would help to change that way of mobility. This is a solution based in the simple principle of sharing similar trips and take profit of the space into vehicles, in that way we reduce congestion in roads, travel time, air pollution, and other benefits related with it which will be explained during the study.

One of the principal disadvantages to make ridesharing work well is the difficulty of matching trips between the users. As the technology improves, we are reaching the point to solve this problem, for example with real-time matching. The amount of information that users receive from other users or drivers will help to make a choice. The present study contributes to let the users and drivers know when it worth it to use ridesharing instead of the private vehicle, and which mode of ridesharing. With this argument, the study offers some information to the users who have not used ridesharing services, or the ones who hesitate whether to choose one option or the other.

This study will consider the most important variables that affect the ridesharing, in order to try to establish continuous and generic concepts, or a grading of options, for modeling with the same variables the costs of ridesharing for users and drivers.

1.3. OBJECTIVES

The principal objective of the study is to develop a modeling of the driver and user costs of different modes of transport related to ridesharing. This model will help to decide which kind of transport is more convenient depending on the type of trip and the distance. It is such a complex study that involves a widely range of variables and parameters to adjust, so that a slice of the work is to simplify the modeling to the level of our studies. Because of that, an optimal selection of the data and its use must be done.

Due to the simplification mentioned above, the model has to use similar variables. It is a part of the study objectives to do a taxonomy of the modes of transport depending on their characteristics, and to decide which variables affect to their modeling. These variables are considered continuous within the area of study instead of doing a discretization for each trip, that would be too much complex for the level of the study.

Another point of the work is to apply the model to assign the optimum mode of transport for a trip with specific characteristics. For this reason, the models are analyzed depending on the trip distance, and usually with the number of passengers. With this information, the users can decide easily if, for example, it is worth to have a private vehicle or not.

As the aim of the study was born in Barcelona, it implements the model in that city too, using real data. Due to that, all the estimations are correlated with this region, trying to focus it on commuting and urban trips. Thanks to that, it is possible to summarize some conclusions for future planning of the city transport.

1.4. ROAD MAP

First of all, the study summarizes a literature research about the functionality and the socio-cultural, economic and legal issues related with ridesharing. This is explained in Chapter 2 and will help to understand what ridesharing means and how it works. The modeling characteristics are also studied from different authors, some of them introduced later during the study for a better contextualization.

The Chapter 3 makes a taxonomy of the modes of transport that the study will model, and some related ones that are not fully modeled but are important into ridesharing options too. This classification is done taking into account the relation between the driver condition and the vehicle ownership, and the properties of the service: if there is a payment, if the driver goes alone or if he is a professional and if there are licenses or not. The graduation starts with the private vehicle (total ownership by the driver, who can use it with totally freedom), and finishes with the taxi (no ownership and professional driver).

The next step is to define the variables and parameters that interact on the model. This is done in Chapter 4. It is important to decide which ones of the big amount of variables affect the model with more intensity. These variables are simplified in a continuous way into the area and the time of study like in an aggregated model; it means that the study considers average values in order to adapt the modeling to the requirements and the objectives of this work. These average values can change from one period to another, and the same occurs with one region to another. For this reason, the average values must be chosen carefully according to the region and period of study in order to set a correct reliability of the models. The estimation of values is realized in this chapter for the most frequent and important variables in all the models. In particular, the annual travelled distance, the mean trip distance, the value of time, the total travel time and the costs of service. Whenever it is possible, the estimations are adapted to data related to Barcelona city region, the place where the study is applied. The estimation of the other variables is realized along the models for further comprehension.

The models are presented in Chapter 5. Due to complexity sakes, the study does not take into account the rush hours and congestion charges to formulate them. Every one of the modes presented in Chapter 3 is now modeled with its particularities, but it is important to remark that some models are an adaptation of others. An example of this is the modeling of private vehicle, shared rides for free, shared rides with payment, and even carpooling. All of them use the same model formulation with just a few changes depending on the situation conditions.

In the Chapter 6, the application of the study is done utilizing the software Excel to obtain different results. Some figures and tables are presented because they help to understand the results and analyze the models. All the models are analyzed and compared with respect to the trip distance in order to establish some preferences depending on it.

A conclusion of the study is reflected in Chapter 7. It summarizes the results obtained along the work and the global interpretation of the results, observing if the initial objectives were satisfied. There is also a future research proposal, with the issues where the study did not arrive because of complexity, and with new ideas to motivate other studies.

2. STATE OF ART

2.1. RIDESHARING LITERATURE

The concept of ridesharing involves the process where a user, usually understood as a passenger, joins a trip with a driver in the same vehicle, which can be property of the driver or not. Usually they share the travel costs, such as gas, tolls or fees. Based on Furuhata et al. (2013), ridesharing is such an intermediate step between private vehicles and public transport. It combines flexibility and commodity with fewer costs than a private trip.

The basic definition of ridesharing involves also a traditional sharing of a vehicle that has been done since the carriages exist. Some examples are the families that own a vehicle and overlap their trips to save some costs, the group of friends that rent a car for some days during their holidays, the workers that contact with co-workers for sharing their trip, hitch-hiking, and many different situations are involving a kind of ridesharing. This kind of ridesharing is such a traditional way of sharing the trips.

It was after the WWII that the government of the U.S. created the first organized form of ridesharing, according to Furuhata et al. (2013). It was a policy to reduce fuel consumption, and it worked using a bulletin board for the arrangements. Other authors such as Ferguson, E. (1997), also have studied the history of carpooling. Then, on the 1970s, the oil crisis led some companies, such as Chrysler and 3M, to establish a “vanpooling” program for the employers. This was a way of using vans shared by the employers for commuting. Here was when the carpooling concept was born.

Other authors use also the term of carpooling, except the British ones who talk about carsharing as the same concept¹. The differences between ridesharing and carpooling are that ridesharing comprises also taxi and bike rides, and generally longer trips than carpooling. Carpooling is commonly used for commuters who share the same car and trip with regularity. Hence, ridesharing is a general concept that involves all that alternative modes of transportation, such as carpooling or taxicabs, where the users share the vehicle and the costs for the trip.

The initial problems of carpooling were related with the inflexibility of schedules, because of the turns between the drivers. For this reason, the concept of dial-a-ride was born, in order to pre-arrange the ride adapted to particular necessities. This has encourage the research until the creation of the matching services, like the research done by Agatz et al. (2012). The dynamic ridesharing, defined in the next section, is the modern result of this.

In the context of searching more flexibility, the spontaneous ridesharing was born with the objective for the drivers of using the High-Occupancy Vehicle (HOV) lanes. It was more flexible than traditional carpooling because no pre-arrangement was needed, and the service was not led by any organization but by the drivers themselves. The problem was that a special meeting location with high demand was needed².

With the development of Internet, some private companies developed digital services for matching the users. These matching services were focused on two kinds of demand: commuting and long-distance trips. In the present study, the application of the models will be focused on commuting trips, more concretely in the city of Barcelona. These private companies obtained their

¹ Jonuschat, H. and Handke, V. (2013).

² Furuhata et al. (2013).

benefits from advertisement fees and government subsidies, so that no commissions were applied to the users.

According to Furuhashi et al. (2013), even with Internet-based matching services, the use of carpooling for working has decreased a 10 % in the last 30 years. It means that more innovations are necessary to solve the problems that inhibit ridesharing, for example, the development of GPS and smart phones is such an innovative great tool that permits the real-time matching. Some matching companies use this in addition to the Information and Communication Technologies (ICT) for creating instantaneous ridesharing. The study Agatz et al. (2012) is focused on how these innovations are introduced into the concept of dynamic ridesharing. A work carried out by Levofsky, A. and Greenberg, A. (2001), classifies ridesharing in *traditional* and *dynamic*, depending on the kind of matching: if it was a long-term prearranged match because the schedules between users are similar and fixed, we are talking about traditional ridesharing; otherwise, for more flexibility in the schedules and on-time arrangements it considers it dynamic ridesharing. On the present work, it is defined as a *traditional ridesharing* the mode where the matching is done directly by the users without a company that helps them; on the other hand, the study calls *modern ridesharing* the mode where the matching is performed through a company, even if the matching is for a long-term. Other studies, Amey et al. (2011) propose the fundamentals for further research, studying how the mobile phones and other applications can help to improve the real-time matching, giving more flexibility to the ridesharing matching services. They define real-time ridesharing as a service on-time without prearrangements.

Nowadays, there are still being uncertainties about the approaches for matching the users, so the companies use different models for their estimations. Usually the users have to pay a distance fare and a ridesharing fee, Furuhashi et al. (2013). The fact that the technology evolves, helps to use this services in a more comfortable way. For example, the payment can be realized in the vehicle but also by electronic payment, and the reputation tools related to the social networks help the users to trust each other.

As a summary of the different ridesharing matching agencies types with similar business function, Furuhashi et al. (2013) proposes the classification shown in Figure 1. The taxonomic criteria is based on primary search criteria and the target markets.

In the present study, a taxonomy of ridesharing modes is proposed. In this case, the taxonomic criteria is based on the ownership of the vehicle, and the conditions of the service (payment, type of company, professionalism of the driver). It is further explained in Chapter 3.

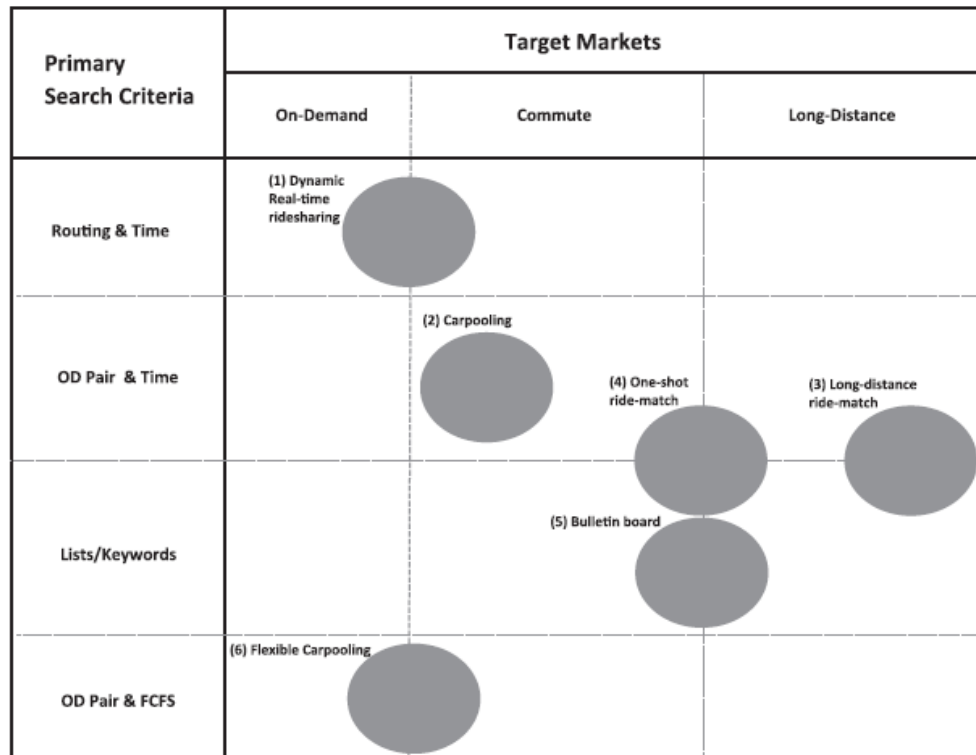


FIGURE 1. Six Classes Of Ridesharing Matching Agencies. [Furuhata Et Al., 2013]

The objectives for both, *users* and providers of ridesharing, are usually the same: reduce the operational related costs of driving, and give the chance to the users to be passengers of the trip, in the case they do not have a better mode of transport. There are private providers who also use the service for making some benefit, as explained by Agatz et al. (2012), and there are also public providers focused on reducing pollution and congestion in the cities.

The principal difficulty of ridesharing as a new way of move is the lack of objective information. Generally, research on ridesharing attitudes is focused on sample surveys to the users to reveal their preferences and collect associated data. After this first step, the data obtained can be used for calibrating the models, like in Morency, C. (2017), with a study applied in Montreal. This calibration is an important issue because the users and drivers behavior can vary considerably depending on the region and the period of study, within other factors. From these surveys, it is possible to construct OD Matrixes that show the origins and destinations of the users. Understanding this behaviors and doing a correct calibration is an essential fact for matching the demand with the supply.

The data collected from surveys conduce to measurement and sample errors, as explained in the book of Stopher, P.R. and Meyburg A.H. (1975). They are related to the estimation of variables, and the expansion of the data-base to the total population, respectively. Modeling ridesharing is such a complex mathematical procedure based on associative relationships instead of physical laws. The lack of objectiveness in ridesharing and its modeling complexity induces the necessity of simplifying the formulations for the models. Specification errors appear due to these simplifications.

According to Stopher, P.R. and Meyburg, A.H. (1975), the optimum complexity for a model is that one that reduces the sum of specification and measurement errors. In the present study, any OD Matrix is evaluated because the modeling does not take into account the particularities of each trip, but the characteristic particularities of the full region of study. This study does a process of

simplifying the variables used for the models, reducing the complexity. In one hand, it reduces the measurement errors. In the other hand, this simplification enhances the specification errors.

Due to this, it is important to perform sensibility analysis and observe which variables have more effect on the modeling, with the objective of calibrating this variables. An example of analyzing a ridesharing model is the paper of Viti, F. and Corman, F. (2013), that propose a modeling for dynamic ridesharing, which has a complex behavior. The formulation used in the present study has a similar approach, but more simple because of the level of the study.

The thesis of Salanova, J.M. (2013) has been a focus of influence for the models presented in this study. Salanova established a modeling for the taxicabs. The modeling takes into account the taxi supply, the waiting time and the demand, that are correlated in a complex bi-linear way. This situation will be commented along the present study, too.

2.2. RELEVANT ATTRIBUTES

2.2.1. FUNCTIONAL

The mobility in the city depends on a complex system of interactions which should be analyzed into this context of interactions. In their work, Linares et al. (2016), it is exposed that the society is changing from a “car ownership” to the “vehicle usage”, and a big contribution for this has been done thanks to the Information and Communication Technologies³.

As it was stated in the Introduction, one of the problems of the success for ridesharing is the communication issues. With a good matching system, more commuters would share they ride leading to a higher occupancy rate in vehicles, so less congestion in the road. Logically, it produces a lower emission of gases that affect the Climate Change. For that reason, it is important to invest and research on improving ICT and computation capabilities related to ridesharing. In the study of Furuhata et al. (2013) there is a classification of the challenges that ridesharing must deal with. According to it, more coordination is needed for the itineraries and schedules between participants.

<< ...ridesharing coordination is an informal and disorganized activity and only in certain cases can travelers make use of ridesharing as a regular transportation alternative.>> (Furuhata et al. (2013)).

The fact is that a lack of communication for the users is an inhibitor of ridesharing. The level of awareness is very low, and the solution of this is based on the development of new communication technologies. Some users affirm that they have no information about the mobility alternatives that exist in their region, even ore for new services such as carsharing or modern carpooling⁴. The goal of the present study is to give information to the users with respect to the costs of a characteristic trip. This can change the traveler behavior, and shift some users to share their trips, reducing the use of private vehicles with single-occupancy, according to Amey et al. (2011).

³ Abbreviated as ICT.

⁴ *Mobility 4.0 - study on digital transformation in mobility & logistics.*
<https://connected.messefrankfurt.com/2017/03/16/mobility-4-0-study-on-digital-transformation-in-mobility-logistics/>

Some authors, Amey et al. (2011), stated the inefficiency of the matching for ridesharing saying that, even if exists a driver and a user who could share their trip, they could not contact each other.

The development of ICT and GPS enhances the use of multi-modal transport, and here we can find ridesharing services. Nowadays, the dynamic-ridesharing puts in contact drivers and users with similar routes and timetables, but the difference with conventional ridesharing is that this matching is done in real-time, so the users have to wait less for their trips, and the matching is done by connecting similar routes for individual trips, Dailey et al. (1999). This is an important fact for the success of ridesharing services, as stated in Agatz et al. (2012). In his work, Agatz explains how many ridesharing commuting chances can exist along a freeway collapsed because of congestion, as congestion is produced in a road by the coincidence of a portion of the different routes of trips.

A description of the variants of ridesharing depending on the number of drivers and riders is done in Agatz et al.(2012), introducing some constraints for the feasibility of matching depending on the trip lengths. The positional elements of ridesharing are explained in Furuhashi et al. (2013), who also introduces a classification of the ridesharing patterns for single and multiple passengers. In the present study, the trip length for the driver is constant even if more riders are picked-up in order to simplify the models. Normally this study considers that the in-vehicle distances are the same for passengers and driver. This corresponds to the Pattern 1 (Identical Ridesharing) in Furuhashi et al. (2013), with the difference that the passengers tend to walk a longer access distance to the pick-up location, and from the drop-off point to the final destination. It is defined as a "point-to-point" route, further explained in Chapter 4.

A "Multiple Passengers Ridesharing System" (MPRS) is studied in Linares et al. (2016), introducing an Advanced Traveler Information System" (ATIS) to determine the routes that satisfy the time constraints of the users. This system, also studied by Levofsky, A. and Greenberg, A. (2001), is not only based on the pick-up and drop-off locations, but also on the traffic forecasting. In the present study, the traffic circumstances are not observed due to their complexity.

All this advances related to the technology will form part of the concept of Mobility 4.0, the new era of the mobility. The most important innovation of this concept is the digitalization and integration of the mobility systems. Some examples are the coordination between users and companies via the smartphones, and their easier matching thanks to the GPS tools.

With the new services, a digital integration of the processes has been accepted for the society, but it has not enhanced yet. Generally, in ridesharing services, the tariffs applied to the users are kilometeric and hourly rates, plus a usual subscription fee. All of this is studied in the next chapters with more precision depending on the mode. What is important is that, the matching is realized via a digital platform that uses ICT technologies. The payment is also realized with security through electronic systems. Some services accept also the direct payment, hand-to-hand, but as the mobility progresses to the new era, the electronic method is becoming more conventional.

Actually, all this improvements, conduct to a better flexibility of ridesharing services. In the last years, the matching between users was realized with enough time for the prearrangement, and usually it was for long distance trips. Nowadays, as it was stated before, with real-time service, the use of short trips without prearrangement is being developed. For the moment, the technology progress has achieved the goal of arriving to a carsharing vehicle, paying it via the smartphone app, and opening it directly with the mobile phone. This kind of progresses will make the ridesharing successful.

Another possible problem that makes ridesharing unattractive, studied by Morency, C. (2007), is when there is a personality conflict between users, that can affect them to the point of do not use this service again. As explained in Furuhashi et al. (2013), some agencies provide a reputation service that allows the users to build trust between them. The typical reputation systems are created with the feedbacks reports from other users and a system of punctuation that allows knowing whether the evaluated users will provide an honest service in the future or not.

The social networks have also an impact on this, because in some matching platforms, the users can access them to have a better background information about who is going to share the trip with them. In some services, such as carpooling, there is the possibility for the users to evaluate their drivers, so that other users can prove the level of security of the driver.

Both studies, Morency, C. (2007) and Furuhashi et al. (2013), coincide on the fact that building a trust between unknown users is fundamental for enhance ridesharing. It is logical to understand that the users want to know their travel-mates before paying them and traveling in their vehicles

Related with the institutional design of ridesharing companies, according to Furuhashi et al. (2013) it is a problem to have too much ridesharing companies serving a specific region. The reason of this is that the demand is fragmented, thus the matching cannot be fully completed by only one agency.

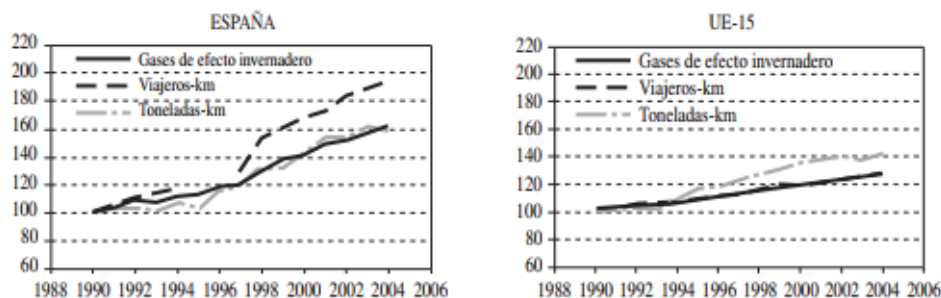
It is interesting to provide extra travel information to the travelers that cannot complete their full trip with a ridesharing trip. In addition, it is a challenge to model a real-time changing service of planning, paying and matching that works with on-time data, such as a real dynamic ridesharing service.

2.2.2. SOCIETY EFFECTS

The use of ridesharing reduces the fuel consumption and emissions. Many authors, such as Agatz et al. (2012), have showed how the ridesharing services help to reduce the distance driven by vehicles, it means that thanks to ridesharing, less vehicles are needed for the same amount of trips, and this produces a reduction of pollution and Greenhouse Gases. In the Figure 2, it is shown how the amount of travelers has increased during the last years, and this has caused an increment on the Greenhouse Gases Emissions.

Pérez, J. and Monzón, A. (2008) state that the emissions are caused by the increment in the demand of transport of goods, rather than by population growth. However, the population growth and its traveling modes also affect to the quantity of emissions. According to Mackenzie et al. (2012), the vehicles are getting cleaner with respect to the environment as the technologies improve. However, during the last years a bigger number of vehicles is performing an offset of this improvements, because even when the cars produce less emissions than in the past, their increasingly usage is producing more emissions than the normal. If this traveling modes and behaviors become more effective, for example using ridesharing services, this emissions will decrease meaningfully, which is one of the ridesharing objectives. It is true that not always the trip distance is reduced by ridesharing, sometimes the number of trips (or the distance) is increased because of ridesharing. This behavior is studied in Morency, C. (2007), stating that in situations such as household-based ridesharing, some family members act as taxi drivers riding along to transport their relatives. For this reason, Morency studied how to discriminate between sustainable and questionable ridesharing trips.

Figura 2. Evolución GEI y demanda de transporte en España y en Europa 1990-2004.



Fuente: elaboración propia a partir de Informe TERM-AEMA (2006).

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FIGURE 2. Evolution of Greenhouse gases and transportation demand, in Spain and Europe 1990-2004. [Pérez, P. J. And Monzón, A., 2008]

About the conservation of fuel, it is important to note the next assumption: if the number of passengers increase on a trip, the load transported by a vehicle is higher so the combustible consumption increases; however, this consumption would be higher if the passengers were using extra vehicles. It means that with ridesharing, many liters of combustible are saved, so that many tones of the emissions commented above, too.

Ridesharing is one of the solutions of having less congestion in the cities, which is one of the principal problems for transportation⁵. Ridesharing palliates the effect of peak hours reducing the number of vehicles in the road. If congestion is reduced, it contributes to a general social welfare for many reasons. In one hand, less pollution, noise, and stress is generated, and even accidents on the road are reduced if less vehicles are circulating. On the other hand, the travel times become lower, and the perception of the time, too, as studied in Victoria Transport Policy (2017). These two facts represent time and money savings for the users. Then, it can be announced that ridesharing affects the congestion, and with less congestion, the quality of life improves, so ridesharing improves the life welfare. As stated in Cervero, R. and Griesenbeck, B. (1988), the probability of share a ride increases with the trip length. In the present study, it is studied how ridesharing alternatives, such as carsharing, are also optimal solutions for short trips, in order to increase this probability of using ridesharing for short trips.

Minimize the travel time is another consequence of ridesharing. It is produced in in different ways: the users that would use slower modes, such as buses, have the chance to travel by a faster vehicle. On the other hand, if the congestion is reduced as stated before, the speeds are higher and the travel times become lower. Some authors, such as Ben-Akiva et al. (1986), have studied how congestion on peak-hours affect to variables related with the time, but this study does not take it into account due to complexity sakes.

In addition, some commuters are able to use HOV lanes thanks to ridesharing. It reduces the travel time comparing to the situation that they travel alone but have to cross crowd roads.

⁵ Cervero, R. and Griesenbeck, B. (1988).

The fact is that higher average speeds conduce to less emissions⁶, as Agatz et al. (2012) clarifies in his study. Then two important social benefits are related with ridesharing: less travel time for users, and less pollution in the cities.

A secondary inhibitor for the users is the fact that for a correct matching, they should exchange their travel data and other information with the agencies and with the other users. This is more such a personal privacy decision, but the fact is that every day, the users of this service are receiving more data protection for palliating this issues.

There is also the problem of the users that think their trip would not be comfortable with a stranger. It is true that sharing a trip is not as comfortable as traveling alone, because of privacy factors. However, from a positive point of view, it is a chance for meeting new people and communicating with a society that is losing contact because of technologies. Fortunately, each time the society is getting used to use this service, because it is evolving to the concept of not needing a private car.

2.2.3. ECONOMIC BENEFITS

For the users of ridesharing as passengers, some costs are eliminated, others are shared with the driver and the rest of users. The most representative costs reduced by ridesharing are the parking and fuel costs. In addition, the travel time can be analyzed as a monetary opportunity cost, and if thanks to ridesharing you move faster, you are saving time but money, too.

In some modes of ridesharing, the users are willing to share their trips in order to divide the operational costs by the travelers. This philosophy is applied to the carpooling mode, where the monetary benefits should be zero, but the drivers have fewer costs than if they travel alone. The users pay a portion of their trips depending on the trip cost, instead of having to own a car and pay its fixed costs.

In other modes of ridesharing, such the case of Uber and Lyft, the drivers search to get some monetary profit from their trips, as professional drivers. These companies also have a benefit: they do not have to pay the fleet expenses, as happens with carsharing, or some taxi companies. However, their principal cost is invested in developing a good matching system. This is studied in Mulligan, D. C. (2014).

There are also secondary economic benefits induced from the reduction of vehicles in the road, and the times of travel. Stakeholders like the employers and the society in general can enjoy this benefits too, when saving money but also times on the road.

2.2.4. LEGAL

The fact is that the governments are investing more in other alternative modes of transport. Some of these should be done, such as bike lanes, for promoting this alternative mobility. However, ridesharing is such an important factor that could make the mobility behavior into a better way, and the governments have never focused on promoting this chance.

The studies demonstrate that ridesharing is one of the solutions to the city congestion. Therefore, it should receive more subventions than, for example, the funds for building parking lots.

⁶ This happens if the accelerations values are low.

It is not all about subventions, the promoting by the government is also a decisive factor. In some cities, like Helsinki, a modern concept of Mobility as a Service (MaaS) is introduced⁷. This is such an innovative system that coordinates the public transport with the private sector with for example taxis and ridesharing services. The government has promoted some monthly packages. The users can buy these packages in order to obtain a certain quantity of trips for the transport modes, and what is important, including ridesharing.

In other cities, the introduction of ridesharing services have been controversial. An example of this is the city of Barcelona with Uber. A huge conflict was born because the taxi drivers were receiving too much less demand than before, even when they are paying a legal license which is so expensive, but allows them to operate as professional drivers. Maybe this is a temporal solution, but the best for the future is not to forbid ridesharing services. Instead of this, some regulatory policies could be introduced. This is what happens in other cities.

⁷ Smart transportation technologies for smart cities | Deloitte University Press, <https://dupress.deloitte.com/dup-us-en/deloitte-review/issue-20/smart-transportation-technology-mobility-as-a-service.html#endnote-7>.

3. A TAXONOMY OF RIDESHARING

One of the objectives of this work is to analyze and classify which kinds of transport are more beneficial and economic for the society. For this reason, first we should make a classification of the different classes and depending on the characteristics of each one. The next different classes have been defined, within the point of view of our analysis, that means considering how and which characteristics are going to affect the study.

The presentation of the modes follows a graduation depending on the vehicle ownership relation and on the driver and user conditions. It starts with the most flexible mode, the private vehicle, where the owner and the only passenger is the driver himself. Then the classification passes through a selection of ridesharing chances until the service of the taxicabs, where the owner of the vehicle is the driver or the company, the driver is a professional, the vehicle is licensed, and the passengers must pay fees and trip commissions.

3.1. PRIVATE VEHICLE

We will consider that the use of a private car refers to the driving of a car owned by oneself. For our study, the owner of a private car will have to deal with the maintenance and other costs. This fact have influence on the model hypothesis, explained in the Chapter 5.

In addition, we will consider that in a private vehicle there is only one occupant: the driver, who at the same time tends to be the owner. The owner of the vehicle is a solo-driver and is not subjected to conditions, as for example waiting time or commission fees, and has more flexibility with respect to the other modes.

The fact that this chance is introduced in the study, allows the later comparison of modes including it. Hence, it is possible to observe how sharing the rides is a good way of moving.

3.2. SHARED RIDES FOR FREE AND HITCH-HIKING

This is a simple way of moving, which is characterized by the use of a vehicle of a friend or relative who takes you in his vehicle, usually for free, because you have the same destination, or just because they do you a favor. Therefore, the owner and driver of the vehicle is someone with proximity to the passengers, which do not pay anything to him. This is what this study calls *traditional* matching, or traditional ridesharing, as a way of matching between the users thanks to a word-of-mouth information context. Of course, the introduction of modern matching services by companies, allow the users to have a wider range of opportunities.

A sub classification of this category is the hitch-hiking, that is defined by travelling with a stranger who accepts you in his vehicle.

The problem of this kind of transport, related to our study, is that it is very complex to predict accurately when a passenger will have a friend who takes you for free, or in the case of hitch – hiking, when someone will take a passenger on the road and where he will arrive.

At the same time, this kind of transport is usually free for the passengers, so one the most economic chances for them. A second problem appears here, because sometimes the passengers offer some money voluntarily.

Because of that, it is very difficult to predict the variables that affect this option; therefore, it is not convenient realize a full model for this alternative and its comparison with other modes has no sense for the users, as almost always, it will be the most economical way of moving for users. However, it must be taken into account as a ridesharing choice and that is why it has been defined.

In addition, having an extra passenger who occupies an empty seat does not increase the vehicle costs more than 5%, as stated by the Victoria Transport Policy Institute (2017). Generally, this is a negligible amount related to the combustible consumption. For this reasons, the study considers that the model used for calculating Private Vehicle costs is also proper for Shared Rides for Free costs approach, if we insert a modification into the fuel consumption depending on the number of passengers.

3.3. SHARED RIDES WITH PAYMENT

This is a particular case similar to the last one. The ownership conditions are the same. The difference is that here the passengers must pay a price for travelling, which usually is just a part of the cost of the travel, shared with the driver and the other passengers if there are.

This is a kind of *traditional* carpooling. Going to the university with some classmates who live in the same place is an example. The modeling of the saver driver who wants the passengers to pay the full trip costs is also considered, but it is not an ethical solution, and the drivers obtain better costs for them but the user costs increase considerably. For this reason, it is better not to take into account this particular situation of the saver driver in the final comparisons, and refer to the normal driver situation when talking about shared rides with payment.

3.4. CARPOOLING

We will consider the carpooling as a way of transport, similar to the shared rides with payment, but with the difference that the users and drivers contact through a digital platform that shows the availability of the trips. The characteristics in this case is the sharing of a vehicle by the owner, who is also the driver, with some passengers who usually are strangers and have to pay a portion of the costs of the trip and the commissions or taxes to the company that manages the platform.

The advantage respect the last section is that thanks to the technology improvements, nowadays we can easily find people who is interested in share a trip with you, and then increase the use of this eco-friendly trend. This is thanks to the matching systems that the companies provide through the digital platforms.

It is very important to announce the philosophy of carpooling: the driver and the passengers share the costs of the trip, but the driver should not take profit from the payments of the passengers in order to obtain some benefits. It is possible to find these arguments in the chapters 5 and 6 of the terms of use of BlaBlaCar⁸, which is the company of carpooling by excellence.

⁸ It can be found through www.blablacar.es.

3.5. CARSHARING

The service of carsharing is a platform that offers a multiuser fleet of vehicles, which is distributed around the city. The users can search online where the closest available vehicles are, and they pay for their use in the means of time and/or distance travelled. Normally a subscription fee should be paid when a user wants to enter to this service for first time. Usually they use this service for a short period of time, such as minutes or hours. A well-known company of carsharing is Car2go, which owns the most extended fleet of carsharing vehicles.

Another particularity of this chance is that they offer a free-floating service, which means that one can take a car where available, then drive around, and park it in a different place. In one hand, this improves the flexibility of the service, even making it close to a private vehicle; in the other hand, the use of public parking spots is a problem for the companies, who must negotiate with the councils for the policies. Most of the carsharing vehicles use electric or alternative energies, and the governments are friendly to negotiate some conditions with the companies.

In the city of Barcelona some start-ups have developed this service to convert the city in a more ecological place. The principal ones are Avancar and Bluemove. The council of the city is now starting to contemplate these solutions in its new Mobility Plan, as secondary ideal solutions to the public transport, for those who need a car⁹

This will be also one of the focus of our work, which tries to reduce the number of private vehicles in the city using better alternatives such this one.

The problem of the carsharing prices is that they increase too much as the time runs. For that reason, it should not be used as a way of travelling around during more than 24 hours. In that case, the companies of car rental offer better solutions. It is important to note that carsharing is a kind of evolution of traditional car-renting, but adapted to short urban trip lengths. The present study is focused on commuter trips, so it is not an important matter to study the long periods of travelling because commuter trips are based on shorter and diary trips.

3.6. PRIVATE TRANSPORT NETWORKS

In this category it is going to be included the companies that offer a private vehicle with a driver for the passengers that have look for it through a mobile app or matching service provided by the company. Then, the users look for a ride in the app, and they can book the closest or cheapest vehicle who will take them as if it was a taxicab. Both cars and drivers must get through a rigorous selection to become professionals of this service.

Some well-known companies are Uber, Cabify and Lyft. The system is very similar to the conventional taxicabs. Because of that, some taxi riders complain about the competence with these companies, which offer better prices because they do not pay that much taxes and the license, as a conventional taxicab does. However, the cost of the trip for the users is lower than in taxicabs, so the drivers receive a lower income for trip.

⁹ *Blog de carsharing · Bluemove*, <https://bluemove.es/es/blog/es-el-alquiler-de-coches-por-horas-la-solucion-para-la-contaminacion-en-barcelona?id=267>.

3.7. CONVENTIONAL TAXICABS

The taxicabs service provides a fleet of vehicles with professional drivers that get payments from the passengers depending on the distance or time travelled. Usually these vehicles are equipped with a taximeter, which computes the fare due. This fare, as well as in other payment modes, can depend on the trip length but also on the travel time, variables that are explained later in Chapter 4.

Another characteristic of this service is that the passenger decides the pick-up and the drop-off locations. In addition, the drivers and the vehicles must have got through a selection process. This characteristics are shared with the private transport networks such as Uber explained before. A difference between these chances is that the taxicabs and drivers usually need a license to operate. This license added to the governmental taxes, make the taxicabs more expensive that other modes, and many workers of the sector are complaining about their working conditions.

3.8. CONCEPTUAL MAP OF THE MODES

In order to summarize the taxonomy explained along this chapter, the Figure 3 is proposed in order to make easier the understanding of the modes behavior and study the variables that will affect them in the modeling.

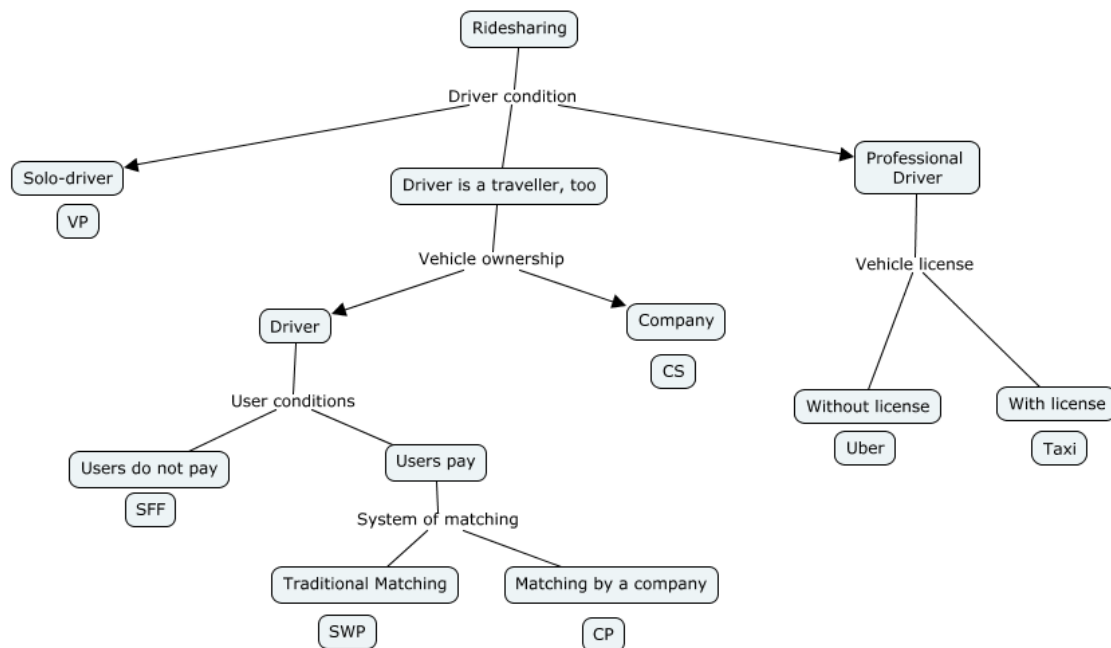


FIGURE 3. Conceptual map for the taxonomy of ridesharing modes.

4. DESCRIPTION AND ESTIMATION OF THE PRINCIPAL VARIABLES

This section introduces the different relevant attributes, variables and parameters that will have an influence on the formulation of the different models.

It is important to understand that the following variables are the most general for all the modes of transport; for this reason, the section gives a brief description of them, not to repeat their characteristics more than once. In one hand, not all of these variables affect each one of the modes; in the other hand, there will be new specific variables that only affect one of the studied modes, so that they would not be introduced in this section but directly in the modeling of the specific mode.

Considering the application of the models to the region of the city of Barcelona, some estimation of the variables is also done in the present chapter. For this, the study takes into account the relation between the estimated values with the possible real values in the region of study. These estimations will be also adapted to the urban and commuting trip characteristics.

4.1. DISTANCE

4.1.1. TRIP DISTANCE

The trip distance (\bar{d}), or trip length, is a leading variable because it affects other parameters such as the travel time, the fuel consumption and the maintenance costs. In real life, all the variable costs are directly associated with the travelled distance.

The range for trip distance will vary between 0 and 100 km. This is because the study considers the initial costs when the user has not used yet the vehicle, and it is related to the fact that the access to the vehicle and waiting time have an influence on the costs. We should also consider that normally the urban trips are of a length of 3 km, but the mean distance from the center to the periphery of Barcelona is 6 km, so within this length, the trips are considered short-urban trips. After the 12 km the study considers the trip as an inter-urban trip, which is the typical for commuters. In the results, it is useful to consider a range up to the 20 km because it is representative for most of the commuting trips, as observed in Autoritat del Transport Metropolità, ATM (2003). The prolongation of the range up to the 100 km in some results is to observe what happens with the costs when the users must do a longer trip.

Due to the simplicity of this work, the study takes into account the average distance trip, measured in km, in order to formulate the different costs. The mean distance for inter-urban obligated trips measured in Catalonia on the 2001 is 14,6 km. This can be observed in the Table 1, as well as an increment of its value with the years. For this reason, it will be acceptable a value of $\bar{d} = 15 \text{ km}$. It is a correct approach of commuters trip length, other studies introduce a mean value of 16,2 km for commuting trip lengths¹⁰.

¹⁰ Hensher, D. A. (2001).

	1981	1986	1991	1996	2001
Distancia media (Km.)	10,8	12,2	13,0	14,4	14,6
Motivo trabajo	10,4	11,6	12,3	13,5	13,9
Motivo estudio	12,1	14,1	15,3	17,4	17,8

TABLE. 1 Mean value of inter-urban trips in Catalonia. [Departamento de Territorio Y Sostenibilidad de la Generalitat De Catalunya, 2012]

4.1.2. ANNUAL TRAVELLED DISTANCE

In addition, the study also considers the annual travelled distance (\bar{D}). It is another important parameter because it is useful to transform yearly costs into kilometric costs. An average annual travelled distance is introduced, but its variations will be analyzed in the next chapter.

It is important to decide a range for the \bar{D} . The study does not consider the option of owing a car without using it, because it is not a normal situation. Usually the owner will rather sell it instead of paying the fixed costs without using it. The Table 2 there is a set of values for different annual travelled distances depending on the driver and vehicle conditions. The drivers that work and have a new car tend to use more their vehicle than the non-workers with very old vehicles.

	Total vehículos	Vehículos de 0 a 4 años	Vehículos de 5 a 10 años	Vehículos de 11 a 20 años	Vehículos de 21 a 50 años
TOTAL	12.562,9 ³	13.889,5 ³	12.784,1 ³	9.729,9 ³	7.891,8 ³
Ocupados	13.426,5 ³	14.448,2 ³	13.552,8 ³	10.871,7 ³	9.675,4 ³
Parados	12.550,4 ³	12.895,4 ³	13.642,7 ³	9.567,0 ³	13.196,6 ³
Inactivos	10.304,3 ³	12.252,4 ³	10.573,1 ³	7.740,2 ³	5.626,0 ³

TABLE 2. Average annual km driven depending on driver and vehicle conditions. [INE, Instituto Nacional de Estadística]

Observing the Table 2, the \bar{D} can be introduced into a range between 5000 km and 15000 km. For the present study, the range will be set from 1000 km to 26500, to observe what happens with the cases when the vehicle is almost non used, and the other extreme, when the vehicle exceeds the quantity estimated of km/year driven. The models work with average values, and the observed average \bar{D} in Spain is 12562,9 km/year.

Because the modeling is applied on Barcelona the average value for the region of Catalonia is studied. As it is observed in Table 3, there is not a substantial difference between the average national value, and the value for the region of Catalonia. For this reason, the range established before is also adequate considering the application to Barcelona. The only difference is that now the average value is 11577,8 km.

	Total vehículos	Vehículos de gasolina	Vehículos de gasoil
TOTAL NACIONAL	12.562,9 ³	10.486,5 ³	14.466,2 ³
Cataluña	11.577,8 ³	9.745,0 ³	14.028,9 ³

TABLE 3. Average annual driven km depending on the type of fuel and the region of study. [INE, Instituto Nacional de Estadística]

For the present study, it is proposed a rounded approximated value that can be valid both for Spain and for Barcelona estimations:

$$\bar{D} = 12000 \text{ km/year} .$$

It is lightly inferior as other literature sources proposed values, because in this way, the costs per km increase and the situation results more critical.

For the Uber and taxi model, another value for \bar{D} is assumed. The drivers in this mode are professionals; for this reason, they should make more trips and more distance during the year. This is further explained in the model proposed in Chapter 5.

4.2. SERVICE LIFE

Its current definition is the expected amount of time or cycles of usage that something can be operated. In this work, it is better defined as the time that a vehicle is used by the owner.

It is very difficult to obtain an average value of service life of a car. It depends on a lot of facts such as maintenance, oil reposition, repairs quality, usage conditions and fuel used, between others. Because of this, the study considers that the maximum number of km before changing the vehicle is 170000 km. It is true that, in good conditions, the service life of a modern car can reach the 300000 km, but we consider a lower distance because usually the owner do not wait until his vehicle stops functioning to change it.

To consider the average value for \bar{L} , we consider the mean value of $\bar{D} = 12000$ km/year. In this way, it is fixed the value of \bar{L} as a constant for all the models that need it. Its value results:

$$\bar{L} = \frac{170000}{12000} = 14.17 \cong 14 \text{ years}$$

This value coincides with some statistics newspapers information¹¹. Thus, it is a tolerable common value.

As it depends on \bar{D} , in the taxi model it should be estimated again obtaining a new \bar{L} .

4.3. MAINTENANCE

The maintenance costs of a vehicle are the expenditures related to the checks and reparations realized in order to have the vehicle in good conditions.

To compute the maintenance cost, the study join up the cost of labor, repairs and new tires into an average value.

In the real life, the maintenance costs depend on the number of km travelled. This cost increases as much as a vehicle is used. Nevertheless, this study considers that the maintenance is a fixed cost. The reason of that is because in other models the variable costs are divided by the

¹¹ See *¿Cuál es la duración media de un coche? | Pruebaderuta.com*.

passengers, and our study considers that the maintenance cost is an ownership issue. Hence, the passengers do not have to pay this cost.

Considering the maintenance a fixed cost, it is estimated as a constant annual cost, that when is divided by \bar{D} is transformed into a kilometric cost. Therefore, it can be related with the trip distance. This procedure is also used for the rest of the fixing costs, resulting in kilometric costs. For this reason, the results of the model will be linearly dependent with the distance. The estimation of the maintenance cost is realized in the first model of the next chapter.

It is important to remark that the results can show a higher value for fixed costs than expected, because of the maintenance introduced as a fixed cost.

4.4. TIME

4.4.1. VALUE OF TIME (α):

The Value of Time¹², represented by the parameter α , is one of the most important parameters for both the drivers and the passengers. It represents the monetary value of an hour, and can change depending on the user characteristics, on the moment and on the travel conditions or type of trip¹³¹⁴. For business travel, the VoT is considered higher than for personal trips, it can be observed in Table 4. In the case of commuters, this study considers that the VoT should be considered into a middle point of both kinds of trip, business and personal. This is consideration can be found in Ayala, R. (2014).

To study the average VoT, a high number of users, situations and moments must be analyzed. Ayala, R. (2014) considers that the estimation of VoT for business trips can be done considering data based on the salaries; however, for personal trips, an empirical estimation based on surveys is required. As an example of the diversity of the VoT, it has been studied that its value is lower for recreational travel than for commuting, as well as it is lower for passengers than for drivers¹⁵. It is possible to find different approaches from different authors. In the adapted Table 4 there are some plausible ranges of values depending on the type of trip:

¹² Expressed as VoT.

¹³ Small et al. (2005).

¹⁴ Ian Wallis Associates Ltd (2014).

¹⁵ Ayala, R. (2014)

Category	Surface Modes* (except High-Speed Rail)	
	Low	High
Local Travel-		
Personal	\$8.60	\$14.70
Business	\$19.30	\$29.00
All Purposes **	\$9.10	\$15.40
Intercity Travel -		
Personal	\$14.70	\$22.10
Business	\$19.30	\$29.00
All Purposes **	\$15.70	\$23.60

TABLE 4. *Pausible ranges for hourly VoT savings (\$/person-hour).* [Ayala, R. (2014)]

From the Table 4 the range values for the VoT can be established. It is important to remark that this approach has been realized with data from the U.S. and on the 2012¹⁶. For the analysis of the models, it is assumed a range between 6 €/h and 22 €/h. Another observation from some studies, Ayala, R. (2014), is that the VoT increases with the distance in personal trips, factors such as the probability of accidents produce this variation. However, in the present study it is considered that the VoT is a parameter independent of the travelled distance.

In their study, Lu, C.-C., Zhou, X. and Mahmassani, H. (2006), they propose a mean VoT of 16.5 €/hour¹⁷. The book of Stopher, P. R. and Meyburg, A. H. (1975) shows a study that is carried out in a region of interest for our work. In their study they propose the mean value of 9.85 €/h for standard vehicles when travelling short and medium distances, that are the usually travelled lengths by commuters.

For the models it is assumed a value of $\alpha = 10$ €/h. It is bigger than the one proposed by Stopher, P. R. and Meyburg, A. H. (1975), but it is a measure convenient due to the actualization of the euro rates and because then, the costs are more elevated assuming, for example, part of the pollution costs.

The VoT is a useful parameter for modeling the cost per kilometer of a trip; it converts the travel time into a monetary value, due to the relation of this time to the decision of mode choice for travelling. The VoT represents the monetary amount that a user will accept for saving a unit time. It means that if a mode offers a trip with low service costs, but high travel time, this travel time becomes also a cost because it is transformed into an opportunity cost of realizing other activities.

4.4.2. TOTAL TRAVEL TIME (TT)

It is assumed as the time spent by a user or driver, from its first location to its final destination.

¹⁶ The exchange rate in March of 2012 was 1 US\$ = 0.746 EU€ (<http://www.datosmacro.com>).

¹⁷ Converted with the rate in March of 2006: 1 US\$ = 0.826 EU€ (<http://www.datosmacro.com>).

The Total Travel Time, also called T_t , is composed by the sum of the different periods that belong to a complete travel. It means that the access time (T_a), the waiting time (T_w) and the in-vehicle time (T_v) are incorporated within the Total Travel Time. With this definition, the next formula is proposed:

$$T_t = \alpha_a \cdot T_a + \alpha_w \cdot T_w + \alpha_v \cdot T_v$$

Where:

$\alpha_a, \alpha_w, \alpha_v$ are coefficients related to the perception of the time for access time, waiting time, and in-vehicle time respectively.

As it is observed in Table 5, Salanova, J.M. (2013) proposes the next average values for the coefficients above. However, in the present work, it is assumed that $\alpha_a = 1$ because it is considered that walking has a positive influence that cannot suppose an extra cost for the modeling, walking should be treated with respect as a natural human behavior for traveling. In addition, the distance walked by the passengers could have been a distance travelled by their own vehicle if they used private vehicle instead of ridesharing. Normally, it reduces the distances travelled by vehicles, so this distance made by walk is not considered a negative factor in the model, such as the waiting time. The waiting time supposes an extra costs because it is not such a positive factor neither for the drivers nor the users, and the perception of it is understood to have a very negative impact in society.

Value	In-vehicle time (τ_{IV})	Walking time (τ_A)	Initial waiting time (τ_w)
Average	1.0	2.2	2.1
Range	1.0	0.8-4.4	0.8-5.1

TABLE 5. *Coefficients of importance of T_t components for work trips.* [Salanova, J.M. (2003)]

For the reasons exposed above, this coefficients have the next values in the present study:

$$\alpha_a = 1$$

$$\alpha_w = 2.1$$

$$\alpha_v = 1$$

Every component of the T_t depends on the area of study characteristics and on the kind of service or company too. For this reason, it is very complex to calculate them with high accuracy. To solve this problem, the model will consider average values for the estimations, adapted to each area of study and to mode of transport.

It is not considered the decision from the drivers of using alternative routes in order to avoid traffic congestion or tolls. This measure is for simplifying the travel circumstances between origins and destinations. The models consider that the origins and destinations follow a point-to-point route. Which means the users decide whether to get into a trip or not, if their destination is the same one of the driver, or does not varies too much, and the origin point also coincides approximately with the driver initial location and time.

Usually in Carpooling there is also the chance that some users will get into the vehicle along the way, if the driver has approved intermediate stopovers. The same happens with the drop-off stopovers. This represents an extra time for picking-up and dropping-off these passengers, and

often it means an extra distance. Instead of this, the simplifications of this study do not consider an extra distance for picking-up or dropping-off the passengers, and their sharing system stills being the same (not less costs for the users that do not complete the full trip distance). The stopovers are introduced into the already planned trip route, so the trip distance stills being the same. However, what is considered in the study is the extra time spent in picking-up and dropping-off these passengers, into a simplified formulation further explained in Chapter 5.

It is important to remark that, the fact that in the present study the traffic congestion is not considered, no variations on the perception coefficients, neither on the velocities and waiting times is induced by peak-hours conditions, as in real-life do.

4.4.2.1. ACCESS TIME

In this study, it is the period of time required to arrive to the vehicle by walk, from the initial location, or to get by walk from the vehicle to the destination. This study proposes an approach based on the case of application to the stand taxi market by Salanova, J.M. (2013).

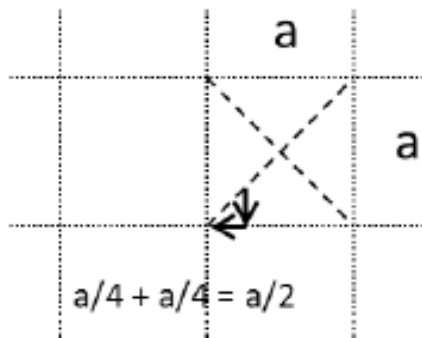


Figure 4. *Access Distance In An Orthogonal Network.* [Salanova (2013)]

In the Figure 5 it is shown how to compute the average access distance for an orthogonal network. For the application of the study in the city of Barcelona, the assumption of an orthogonal network is done, based on squares of 113,3 m of length¹⁸. Hence, the access distance is calculated using a rectilinear distance, and is equal to:

$$A_D = \frac{a}{4} + \frac{a}{4} = \frac{a}{2} = \frac{113.3}{2} = 56,65 \text{ m}$$

Where:

A_D is the access distance, assuming that the vehicle is parked in a city block within the driver initial location.

a is the length of the square that constitutes the orthogonal network.

¹⁸ This geometry was proposed in the “Plan Cerdà”, as explained in Dalmau Salvia, J. (1972).

To compute the access time, this study considers that normally the A_D must be traveled twice, at the beginning of the trip and at the final. It is also assumed that the mean walking velocity is $\bar{v}_w = 1.4 \frac{m}{s} = 5.04 \text{ km/h}$, as proposed in Ji, T. (2005) for people walking into shopping centers, so when the place is crowded.

With this, it is assumed a normal access time formulated as:

$$T_a = 2 \cdot \frac{A_D}{\bar{v}_w} = \frac{a}{\bar{v}_w} = \frac{113.3}{1.4} = 80.93 \text{ s} = 1.35 \text{ min} = 0.0225 \text{ h}$$

In some models, such as the shared rides for free or with payment and carpooling, an extra access distance is introduced. This is because the passengers must walk a higher distance respect to the driver, who is the owner of the vehicle and has it parked in a spot closest to his place than the passengers. Because of this, the study assumes that:

$$T_a = \kappa \cdot 2 \cdot \frac{A_D}{\bar{v}_w} = \kappa \cdot \frac{a}{\bar{v}_w}$$

Where κ is a coefficient relative to the number of times that the users are willing to do the A_D in order to access the vehicle.

There is a constraint for the access distance in order to make it affordable for a user:

$$\kappa \cdot 2 \cdot A_D \leq 700 \text{ m}$$

Over this limit, other modes of transport would be more attractive.

For drivers this coefficient is $\kappa = 1$, as for users in carsharing model. For users in shared rides for free or with payment and for carpooling, it is assumed a tolerable value of $\kappa = 6$, which produces a tolerable mean value of about 8 minutes in the present study application case. It means that, for example, a passenger is willing to walk 6 times the A_D to the picking-up location, and again 6 times the A_D to go from the drop-off spot to his final destination. Assuming a maximum total access distance of $\kappa \cdot 2 \cdot A_D = 700 \text{ m}$, the maximum integer value for κ is 6, that is the reason of choosing this coefficient.

In a trip of 1 km, a pedestrian at 1.4 m/s takes about 12 minutes to do it. In this case, with an access time of 8 minutes plus a trip with a vehicle at 40 km/h along 1 km, it takes 9.5 minutes to make a trip even longer because the access distance is not taken into account within this kilometer. So it worth it in means of time to walk this extra distance.

Another exception is done for the private transport networks such as Uber, and conventional taxicabs models. The driver in this case must drive to the users location. It means that the access time for the users is null, while the access time for the drivers is:

$$T_a = \frac{\bar{d}_u}{\bar{v}}$$

Where:

\bar{v} is the average speed for taxis.

\bar{d}_u is the mean distance between taxi or Uber drivers and their users location.

The Figure 6 shows the distribution of normal frequencies of distances between drop off and pick up locations for the case of yellow taxis in New York. Based on this, the present study assumes the value studied by Noulas et al. (2015) of $\bar{d}_u = 2.097 \sim 2.1 \text{ km}$. In better approaches, this value must be calibrated to the case of Barcelona depending on the demand and the supply. This is very complex to study and need accurate data. Anyway, for the objective of this study it is tolerable to assume the proposed value.

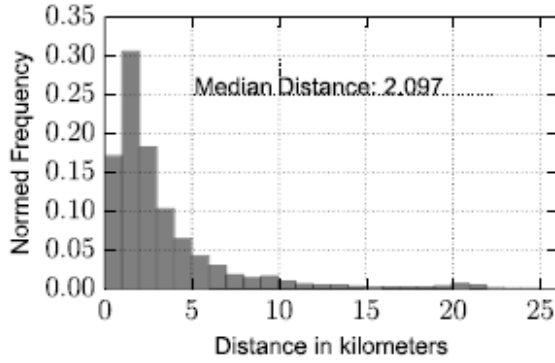


FIGURE 5. *Distribution of distances between drop off and pick-up points for yellow taxi journeys in new york. [Noulas, A. Et Al. (2015)]*

The Table 6 summarizes all the different T_a explained above depending on the model or mode of transport. The abbreviations of the models are explained in Chapter 5.

	VP	SFF/SWP	CP	CS	TC
Driver	$\frac{a}{\bar{v}_w}$	$\frac{a}{\bar{v}_w}$	$\frac{a}{\bar{v}_w}$	$\frac{a}{\bar{v}_w}$	$\frac{\bar{d}_u}{\bar{v}}$
User	-	$6 \cdot \frac{a}{\bar{v}_w}$	$6 \cdot \frac{a}{\bar{v}_w}$	$\frac{a}{\bar{v}_w}$	0

TABLE 6. T_a For drivers and users depending on the mode of transport.

4.4.2.2. WAITING TIME

In this study, the waiting time represents the time invested in the trip while no physical movement is done. It means the period while acceding the digital platform of the services and find which vehicle is the adequate for your trip, and the situations when the driver or the user have to wait in the pick-up location due to the lack of coordination. For this reason, the waiting time depends considerably on the efficiency of matching services.

Actually, a better matching service produces more demand, and if the supply is not increased enough, the waiting time can increase. The point is that if the waiting time is higher, the service is less attractive so the demand decreases. This relation between waiting time with the matching services is crucial because of the demand. The problem is that it is such a bi-linear relation very complex to study, that needs to be solved using iterative methods of optimization. To simplify the models, the study only considers the fact that the more efficient the matching service is, the less invested waiting time.

Salanova, J.M. (2013) studied how, for a constant demand, if the taxi supply increases, the waiting time for the customers decreases. However, the driver cost also increase, as we can see in Figure 7. Point A represents the maximum supply level for a non-profit situation by taxi services. To find the solution of this kind of problems is complex and a good data-base to calibrate the models is needed for its real-life application, even more when the demand is not constant.

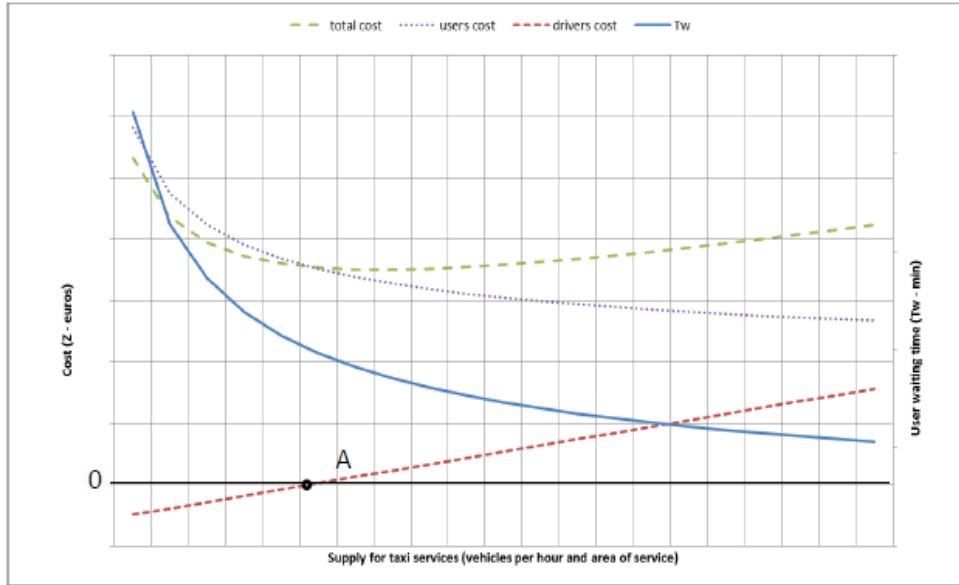


FIGURE 7. *Waiting time, driver, user and system costs for different taxi supply levels in the dispatching market. [Salanova, J.M. (2013)]*

The point A of Figure 7 is known as the second best solution, by Salanova, J.M. (2013). The first best solution is the one that minimizes the total costs, it reduces the waiting time but it supposes a negative benefit for the drivers. In this study, for dispatching-markets such as carpooling and taxi, it is considered the second best solution, where at least a zero benefit is considered for the drivers so that they compensate the operational costs with the income. It means that the waiting time is increased respect to the first best solution.

Due to the considerations explained before about the complexity of estimating waiting time depending on the demand and other factors, this study considers average random values. Only in the services provided by a company (Carpooling, Carsharing, Uber and Taxicabs), the T_w associated with the level of efficiency of the matching services.

The study assumes that for the private vehicle, the shared rides for free and the shared rides with payment models, the waiting time for the driver is null as he starts the trip when he arrives to the vehicle.

The estimation of the other waiting times is based on the simulation results of Salanova, J.M. (2013), considering that traditional ridesharing is similar to a stand market model, where $T_w = 65 s = 1.08 min$, and that company matching services ridesharing has similarities with the dispatching market model, where $T_w = 135 s = 2.27 min$.

These similarities are because, in traditional ridesharing, the users can wait the driver in the door of his house, or even in front of the vehicle, and usually they arrive before the driver does, but not too much. On the other hand, in modern ridesharing service modes, the average value for T_w is higher because, not only the users and driver should access to the platform for the matching

process, but sometimes the coordination is not optimum and they must wait for a while in the picking-up locations.

In Carpooling there is an extra waiting time produced by the consideration explained before about the stopovers along the way to pick-up users. For simplifying the estimation of the number of passengers that will be pick-up once the trip has started, the model considers that only the half of the passengers has been picked up on the stopovers. Hence:

$$T_e = \frac{n}{2} \cdot t_0$$

Where:

T_e is the extra waiting time in Carpooling mode.

t_0 is the average waiting time for one user in Carpooling mode.

n is the number of passengers without taking into account the driver.

The driver of a Carpooling vehicle also has to enter the platform and put an advertisement of the trip, so this is considered another user waiting time. For this reason, it is assumed for that, in carpooling:

$$T_w = t_0 + T_e = t_0 \cdot \left(1 + \frac{n}{2}\right)$$

Another assumption of this simplified modeling for Carpooling is that the users have to wait their own initial waiting time, and half of the driver and other passengers' arrival time. Due to this, their waiting time is formulated with the equation above.

In the Private Transport Network and the Taxicabs modes, the waiting time for the users is:

$$T_w = t_0 + \frac{\bar{d}_u}{\bar{v}}$$

Because they have to access the matching service, but also wait that the vehicle arrives to their position.

In the Table 7 there is summary of the estimation of the different waiting times in our application.

Tw [min]	VP	SFF / SWP	CP	CS	TC
Driver	0	0	$2.27 \cdot (1+n/2)$	2.27	0
User	-	1.08	$2.27 \cdot (1+n/2)$	2.27	$2.27 + d_u/v$

TABLE 7. T_w in min., estimated for drivers and users depending on the mode of transport.

It is important to establish a constraint for the waiting time.

$$T_w \leq 6 \text{ min}$$

If this condition is not achieved, the users could shift their trip into another mode of transport.

4.4.2.3. IN-VEHICLE TIME

It is the time spent by the driver and/or the users inside the vehicle traveling at a certain speed to make a trip. The formula for this time is:

$$T_v = \frac{\bar{d}}{\bar{v}}$$

Where \bar{v} is the average speed of cars on the region of study.

For the present study it is proposed that the average speed for taxis, \bar{v} , is the same as for cars in urban and commuting situations. For this reason, its estimation is based on Salanova, J.M. (2013), who analyzes a data-base of taxis during 4 years obtaining that $\bar{v} = 30 \text{ km/h}$. The fact is that, for short commuting or short inter-urban distances (less than 10 km), the average speed in urban areas is about 25 km/h, but for longer inter-urban distances (more than 17 km), this value increases to 55 km/h approximately, as mentioned in White, M.J. (1988). It should be taken into account that 30 km/h is a tolerable value within this range, but for long distance trips, it is such a low value that can cause inefficiency with respect to other transport modes. Hence, the costs of the trips longer than 17 km, would be higher in the present models than in reality are. For this reason, an analysis with higher average speeds should be done in the results.

The Table 8 shows the average speeds in catalane road network. Considering that in highways the limit is 120 km/h, a range between 25 km/h and 111 km/h can be used within the metropolitan area of Barcelona. For urban trips of less than 17 km, the average speed is 30 km/h and for long-distance commuters it is assumed as 55 km/h. It is not taken into account a high value like 111 km/h as an average speed because this measurements in Table 8 have been made directly in the highways, without taking into account links. Our study does not take into account links, but do not consider that the full trip is on a highway either.

Tipus de via	Vm
Xarxa arterial metropolitana ⁽¹⁾	110,9
Autopistes	125,1
Autovies ⁽³⁾	100,5
Autovies ⁽⁴⁾	112,5
Carreteres convencionals, vies preferents i cc. desdoblades	78,1

TABLE 8. Average speeds in km/h in Catalonia road network, 2003 and 2004. [Servei Català de Trànsit, Generalitat de Catalunya]

4.5. COST OF SERVICE

It is the expense of providing a service, and in this case, the service is travelling. In other studies it is defined as operating costs ¹⁹. To calculate this cost it is better to decompose it into the following typical expenses of travelling with cars. It is important to remark that the data of the different countries and regions indicates the average values of that expenses depending on where the study is applied. Working with average values contributes to eliminate the variation of the service costs due to different driving patterns and conditions that are not studied in this work.

4.5.1. COMBUSTIBLE

4.5.1.1. COMBUSTIBLE COST

Within this cost, there are the fuel and oil costs and their respective taxes. To simplify it, it is better to consider the average value of the sum of them.

The models of the present study consider that the distribution of gasoline and diesel cars are both approximated to the 50%²⁰. Due to that, no weights are needed to calculate the mean combustible value.

To obtain its average value, it is necessary to obtain some data. The Figure 8 and Figure 9 show the variation of the gasoline and diesel prices, respectively, in the last months.

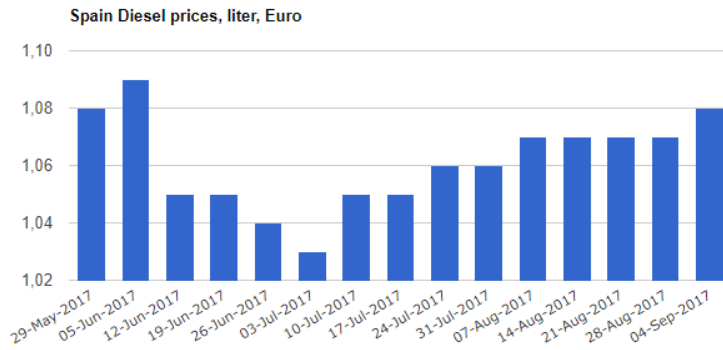


Spain: The data for the country and other countries in our database are obtained from official government sources, regulatory agencies, petroleum companies, and major media sources. We update the data every week.

FIGURE 8. *Spain gasoline prices [€/L].* [Gasoline and diesel prices by country | GlobalPetrolPrices.com]

¹⁹ Mackenzie et al. (1992).

²⁰ Observed in Alegret, X. (2017).



Spain: The data for the country and other countries in our database are obtained from official government sources, regulatory agencies, petroleum companies, and major media sources. We update the data every week.

FIGURE 9. *Spain diesel prices [€/L].* [Gasoline and diesel prices by country | GlobalPetrolPrices.com]

With the data collected, we propose the mean value of the two main combustibles on the last month. So the costs of combustible (\bar{C}) will be fixed as:

$$\bar{C} = \frac{1.21 + 1.08}{2} = 1.145 \text{ €/L}$$

4.5.1.2. COMBUSTIBLE CONSUMPTION

The combustible costs are usually expressed in €/L. The combustible costs vary depending on many different factors: the load, the aerodynamics, the pneumatic condition, the efficiency of the machines, the kind of combustible used, the velocity, and other conditions. For simplifying the formulation of this model, it is useful to consider that the combustible consumption is constant for all the vehicles and conditions. For this reason, it is necessary to know the average consumption of combustible by standard cars (\bar{C}_c).

Some studies and articles propose different values. Marchese, R.A. and Golato, M.A. (2011) have realized a study of combustible and energy consumption depending on the type of vehicle and load conditions. In their conclusions they propose a consumption of 9,47 L/100km for a vehicle with a standard motor. Other informative articles based on national statistics have found a value of 4,98 L/100km for new vehicles in Spanish market²¹. For the present study, it is important to realize that a major consumption means bigger costs for the mode that consumes fuel, so it is better to consider the consumption proposed for a vehicle with a standard motor, $\bar{C}_c = 9,47 \text{ L/100km}$. It must be observed for the calculations that this units mean that in 1 km, the vehicle consumes 0,0947 L.

A exception must be taken into account on carsharing fuel consumption, as the vehicles of this mode normally use alternative energies.

²¹ EuropaPress (2014).

4.5.2. PARKING

The cost of service of a vehicle should include the parking costs, cited from Mackenzie et al. (1992). It involves the payment of parking lots and the price of parking in public spaces. This study considers a pondered formula to calculate the average costs of parking depending on the facility of finding a free-parking place in the area:

$$P_k = \alpha_p \cdot (1 - \alpha_{fp}) \cdot \bar{p}_k$$

Where:

P_k is the annual average cost of parking pondered by a probability coefficient.

α_p is the probability coefficient of realizing a parking during a trip.

α_{fp} is the probability coefficient of finding a free parking place into the region of study

\bar{p}_k is the average annual cost of parking charges.

The α_p will be considered dependent of the mode. The non-professional drivers, located between private vehicle and carsharing, will realize at least one parking between two trips. So considering the last half of time of parking of the last trip, and the first half of the next parking time, the study estimates that $\alpha_p = 1$ for this models. The different one is the related with Uber and taxicabs, as they realize multiple trips before parking. The taxi model will assume that $\alpha_p = \frac{16 + \frac{1}{20} \cdot 8}{24} = 0.68$, considering that realizes a parking every 20 trips during 8 h of work, and that the rest of time it is parked. Usually the taxi drivers have a garage which normally is expensive. However, in this study it is considered that they do not have to pay these parking expenses if they can park for free. This hypothesis make the parking costs for the taxis lower than in reality, but in this way, it is promoting the taxi sector, which is in decline.

The Table 9 shows an adapted data used to estimate α_{fp} . It makes an estimation the different kinds of parking spots on the city of Barcelona during the period 2011-2015.

11. Circulation					
11.7. Parking in the city. 2011-2015					
	2011	2012	2013	2014	2015
Plazas en superficie	135.928	136.886	132.093	130.430	129.805
Área azul	10.190	10.190	9.280	8.850	8.566
Área verde preferente residente	40.244	40.876	36.527	35.647	36.208
Área verde exclusiva residente	3.986	3.990	3.461	3.392	3.307
No regulado	75.446	75.446	75.446	74.224	73.200
Otras reservas (incluido PMR) (1)	6.062	6.384	7.379	8.317	8.524
Plazas estimadas en subterráneos e internos (2)	654.288	657.020	660.224	662.655	664.312
Vecinos	416.237	417.643	418.625	419.971	421.111
Públicas	141.902	141.902	142.863	142.865	143.009
Reservados	81.855	83.358	84.619	85.952	86.325
Solares	14.294	14.117	14.117	13.867	13.867

TABLE 9. *Parking spots in the city of Barcelona 2011-2015.* [Departament d'Estadística. Ajuntament de Barcelona, www.bcn.cat]

The present study proposes a value based on 2015 data. It considers that:

$$\alpha_{fp} = \frac{\text{Total Free Places}}{\text{Total Parking Places}}$$

Where:

Total free spots is the sum of non-regulated spots, public and sandlots.

Total parking spots is the sum of superficial spots, and subterranean and interior spots.

An hypothesis for the modeling is that the drivers do not have to pay the parking expenses if they can park for free, that is the reason of why it is used α_{fp} .

The results are shown in Table 10, that also indicates the Total paying spots.

2015	
Total free spots	230076
Total paying spots	564041
Total parking spots	794117
α_{fp}	0.39681138

TABLE 10. Estimation of α_{fp} .

The \bar{p}_k in Spain was approximately 393 €/year in the 1985²². It comprises the garages rent plus parking average costs. The present study will consider $\bar{p}_k = 400$ €/year.

4.5.3. TOLLS

The toll is a fee that the drivers must pay to use some roads.

The distribution of the tolls has a big dependence on the geographical situation. The methodology of the study solves this problem taking into consideration a representative average cost of payment of tolls, proportional to the travelled distance.

$$C_{tolls} = \alpha_{toll} \cdot \bar{c}_{tolls}$$

Where:

C_{tolls} is the pondered annual value of charges in the road.

α_{toll} is the probability of having to pay tolls during a trip.

\bar{c}_{tolls} is the average annual cost of a toll.

²² INE, Instituto Nacional de Estadística.

The cost of tolls is considered proportional to the distance because depending on the kind of trip, if urban or interurban, the toll costs will be higher or lower. In the highways, the toll costs increases as the same time as the travelled distance.

In the study Measurement of the Valuation of Travel Time Savings, Hensher, D.A. (2001), it is observed the different increase between fuel costs and toll costs depending on the trip length. Both variables increase due to the driving distance, but with different proportionality. For short trips, or urban mobility, the toll costs result higher than the fuel ones. However, for long trips, or interurban, the fuel costs increases to the point that become higher than the tolls. It means that the toll costs do not increase that much with distance such as fuel costs. Due to this, the present study considers the toll costs into another part of the formulation, isolating the combustible costs, which usually are higher, and computing it as an annual cost.

To set a value for the toll costs, the study takes 0.095€/km²³. It is a kilometric price, but the study converts it to annual cost, just multiplying it by \bar{D} . However, it will be again divided by \bar{D} in the models formulation. As we introduced before, this procedure is just to make a pack of parking, toll, and fines costs into the Cost of Service, because the announced variables have less influence in the models.

For the estimation of α_{toll} it is considered that if the trip is passing by a toll way, the vehicle will drive along it and not by alternative ways. In the 2015, there were 278 km of toll ways in the province of Barcelona, and 427 km of high capacity freeways, so a total of 705 km of highways, compared to the 3959 km of total distance of roads in the province²⁴. With this data, the study proposes the next estimation:

$$\alpha_{toll} = \frac{278}{705} = 0.39$$

This is considering that the trips are realized in high capacity roads. However, for urban trips, this coefficient should be reduced because the probability of having tolls or using highways is lower, but it can be considered as an air pollution or congestion toll. It is difficult to estimate the probability of paying a toll, but these costs are not the ones that influence more to the modeling.

4.5.4. FINES

A traffic fine is a monetary punishment for violating the traffic laws. The study considers also the probability of paying a fine for the operating costs calculation.

$$F_i = \alpha_f \cdot \bar{f}$$

Where:

F_i is the pondered annual cost for driving fines.

α_f is the probability of having a fine while driving.

\bar{f} is the average value of a driving fine.

²³ Based on information of <http://www.tolls.eu> that estimates it as 9.5 €/100km.

²⁴ Data from the *Catálogo y evolución de la red de carreteras*. Ministerio de Fomento, Gobierno de España (www.fomento.gob.es).

To estimate \bar{f} we consider the critical case of receiving a fine each year. It is tolerable a value of 100 €/fine as some sources propose²⁵. These two conditions are correlated to obtain:

$$\bar{f} = 100 \text{ €/year}$$

This study has based the estimation of the value of α_f on the data obtained from governmental traffic national institutions²⁶. On its database, there is the quantity of denouncements for traffic laws violation on the 2016, equal to 4.387.229, and the register of drivers on the same year, equal to 26.514.026 people. With this data, we can calculate α_f as follows:

$$\alpha_f = \frac{4387229}{26514026} = 0.165$$

4.6. DRIVER INCOME

It is the money received by the driver and generally paid by the passengers. This concept can be confused with the driver benefits. A driver can receive a certain income without obtaining any economic benefits. This is, for example, the carpooling philosophy.

The next principle is proposed:

If $I - C_T > 0$ the driver is earning some money from the income, so the driver obtains economic benefits. The companies and drivers of taxicabs and Uber services look forward this situation.

If $I - C_T = 0$ the passengers are paying the total cost of the trip. It is the case of shared rides with payment, or carpooling drivers such as in BlaBlaCar.

If $I - C_T < 0$ the driver is paying part of the total cost of the trip.

Where:

I is the income received by the driver.

C_T is the total cost of the trip.

Usually when different users share a ride, the driver does not have a personal benefit, the income is rather for paying some parts of the trip cost. That is the philosophy of carpooling and shared rides by a non-professional driver.

It becomes a profession for the driver when he receives a bigger income, as it occurs with conventional taxicabs or with private transport networks such as Uber. In this situation the driver is a professional and needs to receive a benefit.

²⁵ AFI, Analistas Financieros Internacionales (2016).

²⁶ Dirección General de Tráfico, Ministerio de fomento (2017)

4.7. COMMISSION, TAXES AND FEES

The commission (γ) is a fraction of the paid cost by the user (G). This commission serves to produce an income, which is used for paying the infrastructure and management of the service, and to produce a benefit for the company that offers the service.

The commission is applied in carpooling, carsharing, private transport networks such as Uber, and conventional taxicabs. Its estimation is realized along the different models, due to the fact that it has different values for each mode.

Usually this commission tends to be lower for private transport networks such as Uber than for conventional taxicabs.

There is also the subscription fee for the new carsharing users. This is a fixed cost that does not vary with the distance.

4.8. DEMAND AND MATCHING

The definition of demand is the number of trips demanded in a period of time and an area. The magnitude of this variable is expressed by [trips/(hour-m²)] and is used by Salanova, J.M. (2013) for modeling the generalized costs of the taxicabs stakeholders.

For make it simple, this work will consider a uniform demand within the complete area of study. It means that the study will not separate the different focus of demand in the city, because the examination and designation of the different focus is a complex analysis that does not fit with the objective and the level of accuracy of this study. However, the researchers of this topic can carry out further examinations in order to design different focus into a city or area of study.

Ride matching services must be efficient in order to attract demand. When they are deficient, they induce an increase on the waiting time for users and, due to that, a decrease on the demand of ridesharing, Washbrook et al. (2006). However, as studied in Salanova, J.M. (2013) for the taxi market, the relation between the waiting time and the demand is a bi-lineal problem very complex to solve, for this reason this relations are not considered in the present work.

To study how the matching affects, some changes in the number of passengers, as if more or less demand was attracted. Also it is to consider that the access and waiting time can be analyzed, as the simplification of the study takes into account that better matching services affect directly to this times, decreasing their values. The changes on matching levels are considered for the carpooling, the carsharing, and the Uber and taxicabs models.

5. MODELING OF RIDESHARING OPTIONS

In this chapter it is performed a modeling of the different ridesharing alternatives presented in Chapter 3. The application is focused on commuting and urban trips within the metropolitan area of Barcelona. Due to this, the estimations adopted are based on it, some of them have been presented in Chapter 4, the others are presented in the next sections.

The formulation adopted is related to the aggregated models, because it is assumed that the estimated values are applied from a mass, considering that the characteristics and behaviors are the same in all the region of study, instead of taking into account its spatial distribution. This fact allows the model to be formulated with less decision variables and less complexity, but probably less realistic, too.

The objective function is the individual costs for drivers and users in the different ridesharing modes. The principal variables of decision are the trip length, the number of passengers, and the prices of fares and rates. The hypotheses proposed are made to simplify the models.

It is assumed that the principal factor to promote ridesharing is the incentive of reducing the individual costs, so the computed costs are based on fixed and operational costs. For this reason, the congestion and environmental costs for the society produced by the modes is not formulated. In addition, these externalities would need more complex models, not contemplate in the present study.

5.1. PRIVATE VEHICLE MODEL, PV

The first model considers the generalized costs for a driver of a private vehicle. The cost model for the private car considers the next variables, differentiated into two groups: the fixed costs and the variable costs.

5.1.1. HYPOTHESES

For understanding this model, some considerations must be taken.

First of all, the only occupant of the vehicle in this model is the driver. Hence, the driver assumes all the costs related to the trip.

The fixed costs, explained in the next section, are expressed in €/km. It means that they increase with the travelled trip distance. However, if we consider a full year, some of this values are constant and do not depend on the travelled distance. The fact is that it is very complex to set a fixed value for the fixed costs, independent of the trip distance, because the trip conditions can be very different and complex to have the same fixed cost. Because of this, the model has considered them proportional to the distance, simplifying the calculation of the cost of a specified distance trip.

5.1.2. FIXED COSTS (F_c)

Computed as the sum of a portion of the purchase value, the maintenance, the insurance and other taxes such the registration²⁷. The owner of the vehicle must pay these costs even when he does not use it. This is an important observation, because it makes ineffective the chance of having a private vehicle in the case that its use is very low, for the reason that fixed costs usually are high in this chance.

This formula establishes the value of the fixed costs:

$$F_c = \frac{P + \bar{m} + \bar{i} + T}{\bar{D}}$$

With

$$P = \frac{\bar{P}_0}{\bar{L}}$$

$$T = \frac{\bar{T}_0}{\bar{L}} + \bar{T}_x$$

Where:

P is the annual portion paid to cover the purchase value.

\bar{P}_0 is the purchase value.

\bar{L} is the average number of years of service life.

\bar{D} is the average distance travelled on a year.

\bar{m} is the average annual cost of maintenance for the private vehicles.

\bar{i} is the average annual cost of insurance for the private vehicles. It is a financial protection against damages and injuries.

T is the generalized cost of taxes, involving for example the license and registration.

\bar{T}_0 is the average value of license and registration.

\bar{T}_x is the average annual cost of taxes.

P is calculated as the average price of a standard vehicle divided by the average number of years of its service life. Then, it induces that every year the owner of the vehicle pays an amount related to the purchase of the vehicle. The same occurs with \bar{m} , \bar{i} and T . Therefore, if we divide the sum of this values by \bar{D} , we obtain the fixed costs in €/km, which helps with the trip cost calculation due to the reasons explained in the hypothesis.

The next adapted Table 11 shows a set of values that will be used to extract P and T .

²⁷ Fixing the maintenance and the insurance costs as linear functions with the trip length, considering an average value, makes simpler the analysis, instead of varying it with the distance in a quadratic form.

Annex B.8: Spain *Auto-Oil II Cost-Effectiveness Study*
Part III: The Transport Base Case

TABLE 11: AVERAGE VEHICLE PURCHASE COST COMPONENTS, 1996 (98€)

Vehicle Categories	Average purchase price, excl. taxes	Average sales tax (VAT)	Average registration tax	Average purchase price, incl. taxes
Small gasoline car, <1400cc	9.504	1.521	963	11.989
Medium gasoline car, 1400cc-2000cc	17.853	2.856	1.757	22.466
Large gasoline car, >2000cc	25.732	4.117	3.148	32.997
Medium diesel car, <2000cc	13.689	2.190	1.019	16.899
Large diesel car, >2000cc	30.784	4.926	3.755	39.465

TABLE. 11. *Set of values that will be used to extract P and T* [European Comission et. al (1999)]

The next Table 12 indicates the annual value estimations for the insurance, the maintenance, and the circulation taxes costs.

Auto-Oil II Cost-Effectiveness Study *Annex B.8: Spain*
Part III: The Transport Base Case

TABLE 12: AVERAGE ANNUAL DRIVING COSTS (EXCL. FUEL), 1996 (98€)

Vehicle Categories	Average annual insurance costs	Average annual circulation tax	Average annual maintenance cost
Small gasoline car, <1400cc	272	42	500
Medium gasoline car, 1400cc-2000cc	303	75	937
Large gasoline car, >2000cc	374	107	1.377
Medium diesel car, <2000cc	303	61	705
Large diesel car, >2000cc	374	107	1.646

TABLE. 12 *This table indicates these variables values estimations* [European Comission et. al. (1999)]

As it was explained in the section 4.5.1., the distribution of gasoline and diesel cars is considered equal, so no weights are needed to calculate the mean value. The Table 13 presents the mean values of purchase price, the maintenance annual costs, the insurance annual costs, the initial taxes (T_0) including sales tax and registration tax, and the annual taxes of circulation. For this study is enough to consider the medium category cars.

	Po [€]	m [€/year]	i [€/year]	Sales Tax [€]	Registration Tax [€]	To [€]	Tx [€/year]
Gasoline Car	17.853	937	303	2.856	1.757	4.613	75
Diesel Car	13.689	705	303	2.190	1.019	3.209	61
Mean	15771	821	303	2523	1388	3911	68

TABLE. 13 *Calculation of the mean values of purchase, maintenance, insurance, and different taxes.*

However, some of the values presented in Table 13 are a 1996 estimation with ECU actualized to the 1998. The same occurs with the estimations shown in Table 14, but they are obtained from a 2013 survey. If we want to apply it to the 2017, we must consider that the taxes rate and the prices have not varied during the last decades.

	Per Year	Per Vehicle
Fuel	\$2,400	\$1,263
Auto insurance	\$1,440	\$758
Car payments	\$4,800	\$2,526
Car maintenance	\$600	\$316
Parking	\$360	\$189
Public transportation	\$432	NA
Totals	\$10,032	\$5,053

TABLE 14. Average household transportation expenditures. [Victoria Transport Policy (2017)]

5.1.3. VARIABLE COSTS (V_c):

The costs that vary depending on the distance travelled. These costs would not exist in the case that the vehicle is not used. This study proposes a formulation related with the costs of service, and the savings of time. Other models presented in articles are based on this concept, and introduce it into the generalized costs formula, Lu, C et al. (2006).

$$V_c = \bar{d} \cdot C_s + \alpha \cdot T_t$$

Where:

\bar{d} is the average trip distance.

C_s are the costs of service.

α is the VoT.

T_t is the Total Travel Time.

The costs of service of this model are formulated as:

$$C_s = \bar{C} \cdot \bar{C}_c + \frac{(P_k + C_{tolls} + F_i)}{\bar{D}}$$

Where:

\bar{C} is the average cost of combustible.

\bar{C}_c is the average combustible consumption of a car.

P_k , C_{tolls} and F_i have been introduced in the last chapter and are annual average costs.

In the case of a driver alone private vehicle, the $T_w = 0$. Hence:

$$T_t = \alpha_a \cdot T_a + \alpha_w \cdot T_w + \alpha_v \cdot T_v = \alpha_a \cdot T_a + \alpha_v \cdot T_v$$

5.1.4. GENERALIZED COST FORMULA

The proposed model for the Private Vehicle establishes the formula:

$$Z_{dPV} = F_c \cdot \bar{d} + V_c$$

Where Z_{dPV} is the generalized cost for the driver in Private Vehicle model.

As it was announced, this model considers that the driver is riding alone, so it does not model other users' costs.

5.2. SHARED RIDES FOR FREE MODEL, SFF

In the following models, there will be introduced some passengers, also called users. This fact produces some differences in the formulation.

The differences with the last model is that this one considers an increase on combustible consumption, and the T_w appears in the T_t equation. This model introduces the user cost, too.

5.2.1. HYPOTHESIS

This model considers that all the passengers are in the same location. So the T_w will be the same for all of them.

As it was explained in the Chapter 3, the users of this mode do not pay anything for the service, and their only cost is related to the time.

5.2.2. VARIABLE COSTS

The formulation is the same as the model before, but introducing a factor of adjustment of the combustible consumption depending on the number of passengers.

$$C_s = (1 + \delta \cdot n) \cdot \bar{C} \cdot \bar{C}_c + \frac{(P_k + C_{tolls} + F_i)}{\bar{D}}$$

Where:

δ is the increment on the consumption that an extra passenger produces.

n is the number of passengers without taking into account the driver.

5.2.3. GENERALIZED COST FORMULA

The driver costs (Z_{dSFF}) are formulated as before:

$$Z_{dSFF} = F_c \cdot \bar{d} + V_c$$

As far as extra passengers, without taking into account the driver, are sharing the trip, the users cost formula is introduced. In this particular model, the users do not have to pay any commission to the driver, so their costs (Z_{uSFF}) will be generated by the trip time:

$$Z_{uSFF} = \alpha \cdot Tt$$

5.3. SHARED RIDES WITH PAYMENT MODEL, SWP

The new difference respect to the last models is that the monetary payment from the users is introduced. In this model, the users pay directly to the driver.

5.3.1. HYPOTHESIS

This model has the characteristic that the users pay a portion of the Costs of Service to the driver. It is considered that the users do not pay any commission. That is why the study simplifies these conditions dividing the Costs of Service between the passengers. The rest of variables still being calculated in the same way as the precedent models.

There can exist two situations in this model depending on the driver attitude:

- Situation A: the driver who wants the rest of passengers to pay the full Costs of Service because he is offering the vehicle.
- Situation B: the driver who feels that the Costs of Service should be divided with all the passengers including him.

5.3.2. VARIABLE COSTS

In this case, we have that:

- For Situation A:

$$V_{cA} = \frac{\bar{d} \cdot C_s}{n} + \alpha \cdot Tt$$

Where V_{cA} are the Variable Costs for Situation A.

As it is observed in this formula $n \neq 0$. Therefore, at least one passenger must be travelling possible the condition that the variable costs are not paid by the driver. To work with $n = 0$ it is considered that the conditions are the same as in PV model, so this case must use the formulation proposed in the PV model.

- For Situation B:

$$V_{cB} = \frac{\bar{d} \cdot C_s}{n + 1} + \alpha \cdot Tt$$

Where V_{cB} are the Variable Costs for Situation B.

It is of interest to observe that if $n=0$, the driver costs for Situation B are again the same as for Private Vehicle model drivers, where the driver has to pay all the costs because there are no passengers.

5.3.3. GENERALIZED COST FORMULA

Because of this, the model introduces their respective generalized cost formulation:

- For Situation A:

$$Z_{dA_SWP} = F_c \cdot \bar{d} + \alpha \cdot Tt$$

Where Z_{dA_SWP} is the Generalized Cost for Situation A in SWP model.

For this model, the user costs (Z_{uA_SWP}) in this situation are:

$$Z_{uA_SWP} = V_{cA}$$

- For Situation B:

$$Z_{dB_SWP} = F_c \cdot \bar{d} + V_{cB}$$

Where Z_{dB_SWP} is the Generalized Cost for Situation B.

- The user costs (Z_{uB_SWP}) in this case are:

$$Z_{uB_SWP} = V_{cB}$$

It is very important to remark that, if $n = 0$, the model with the conditions proposed, has the same results as the Private Vehicle model, so when we consider the driver alone.

5.4. CARPOOLING MODEL, CP

In this mode of ridesharing, the study introduces the driver income of the trip from the users, and the commission for the company that provides the service.

5.4.1. HYPOTHESES

The philosophy of carpooling companies and its users is to reduce the generalized costs by sharing the operating costs by the drivers and passengers, not for the driver to make a profit. So this cost is used for paying a portion of the operation costs to the driver and the commission to the company that offers the infrastructure of the service.

In the Chapter 4, it was explained how the model considers some stopovers along the way. The hypotheses to simplify this is that it influences only on an extra waiting time. The trip distance and the division of the costs stills being the same as if non stopovers were introduced.

5.4.2. VARIABLE COSTS

As it has been stated above, in the carpooling mode, all the passengers share the Cost of Service. However, this model considers that only the driver pays it, but part of it is compensated with the

driver income, as it is studied below. For this reason, the model retakes the formula of the last models:

$$V_c = \bar{d} \cdot C_s + \alpha \cdot Tt$$

With

$$C_s = (1 + \delta \cdot n) \cdot \bar{C} \cdot \bar{C}_c + \frac{(P_k + C_{tolls} + F_i)}{\bar{D}}$$

5.4.3. DRIVER BENEFIT

The fact that in the following models it is introduced an income produced by the passenger's payments, which is managed by a company, induces the necessity of compute the driver benefit. For this reason, it is introduced the concept of Cost of the Trip and the concept of Driver Income in the formulation of the Driver Benefit.

5.4.3.1. COST OF THE TRIP (C_T)

Understood as the part of the operational costs that the driver must offset with the income. In this model it is computed as the operational costs, without taking into account the portion that corresponds to the driver, in order to share the costs in the full sense of the meaning.

$$C_T = \bar{d} \cdot C_s - \frac{\bar{d} \cdot C_s}{1 + n}$$

5.4.3.2. DRIVER INCOME (I)

As it was stated before, in some modes the passengers must pay the service through a company. In carpooling the driver proposes a price for the passengers, g , related to the operation costs, considering that it depends on the trip distance. It is also considered that the commission cost fall on the passengers. Hence, the price paid by one passenger results:

$$G = g \cdot (1 + \gamma)$$

Where:

g is the price of the trip that the driver proposes for one passenger.

γ is the commission coefficient.

G is the total price for the trip that each passenger must pay.

This payment means an income for the drivers. Considering that the driver receives the G from each driver, but then he must return to the company the percentage related to the commission, the driver income is calculated as follows:

$$I = n \cdot G - \gamma \cdot n \cdot g = n \cdot g$$

The commission for CP model is estimated using information from the BlaBlaCar company policies. In the Table 15 there are the different commissions -called "administration fees" by the company- that BlaBlaCar receives depending on g .

Contribución a los costes del trayecto	Gastos de gestión por pasajero (IVA incluido)
1 € – 6 €	1,00 €
7 € – 8 €	1,50 €
9 € – 11 €	2,00 €
12 € – 13 €	2,50 €
14 € – 16 €	3,00 €
17 € – 19 €	3,50 €
20 € – 22 €	4,00 €
23 € – 26 €	4,50 €
27 € – 29 €	5,00 €
30 € – 33 €	5,50 €
34 € – 37 €	6,00 €
38 € – 40 €	6,50 €
41 € – 43 €	7,00 €
44 € – 46 €	7,50 €
47 € – 49 €	8,00 €
50 €	8,50 €
51 € y más	17 % de la contribución a los costes del trayecto, redondeados a los 0,5 € más próximos

TABLE. 15. *Comissions applied by BlaBlaCar depending on the trip prices.* [Condiciones Generales de Uso de BlaBlaCar | BlaBlaLife, <https://www.blablacar.es/blablalife/lp/gastos-de-gestion>]

In the Table 16, there is a mean contribution calculated from the ranges of g shown in the table above. Dividing the fees of Table 12 by the mean contribution, the average percentages of the commissions respect g are obtained.

Mean contribution [€]	Comission [%]
3.5	0.285714286
7.5	0.2
10	0.2
12.5	0.2
15	0.2
18	0.194444444

21	0.19047619
24.5	0.183673469
28	0.178571429
31.5	0.174603175
35	0.171428571
39	0.166666667
42	0.166666667
45	0.166666667
48	0.166666667
50	0.17
>50	0.17

TABLE 16 Comissions in % applied by BlaBlaCarr depending on the trip prices.

From the table above, it is possible to observe that the commission percentage is around 17 %. So, for this model, it is assumed that $\gamma = 0.17$. It is true that the percentage increases up to 20 % or more when the mean contribution has a value under the 15 €. Nevertheless, imputing a lower percentage will help the users to have lower cost and, in this way, they will be more encouraged to use this mode of ridesharing.

5.4.3.3. BENEFIT CONDITION (B)

Recalling the carpooling philosophy, the driver must not obtain benefits from its income. This income must be used for paying the C_T .

For this reason, the next condition must be followed, taking into account that the shared costs by driver and passengers are the Costs of Service, as defined with C_T :

$$B = I - C_T = 0$$

$$B = I - \bar{d} \cdot C_s + \frac{\bar{d} \cdot C_s}{1 + n} = 0$$

That can be also expressed as:

$$g \cdot n - \frac{\bar{d} \cdot C_s \cdot n}{1 + n} = 0$$

Following the condition, it is obtained an approximation for the fair g proposed by the drivers:

$$g = \frac{\bar{d} \cdot C_s}{1 + n}$$

As it is showed, g increases with the trip distance and the kilometric costs of service, and it decreases with n .

This approach is made in order to compute a fair price for the passengers within the condition that $B = 0$. Actually, the drivers do not know beforehand the number of passengers that will share their trip. Due to this, they opt to propose their own approximated prices, considering that the demand of passengers will vary depending on them. The modeling of this behavior has an important complexity, so this study assumes an analysis on the costs related to different g , but without correlating it to the demand.

5.4.4. GENERALIZED COST FORMULA

The formula proposed for the drivers cost (Z_{dCP}) in this model is:

$$Z_{dCP} = \bar{d} \cdot F_c + V_c - I = \bar{d} \cdot [F_c + C_s] + \alpha \cdot T_t - I$$

Also expressed as:

$$Z_{dCP} = \bar{d} \cdot F_c + \alpha \cdot T_t + \bar{d} \cdot C_s - g \cdot n$$

As can be seen, if g has the fair value proposed above, the formulation results:

$$Z_{dCP} = \bar{d} \cdot F_c + \alpha \cdot T_t + \bar{d} \cdot C_s - \frac{\bar{d} \cdot C_s}{1 + n} \cdot n = \bar{d} \cdot F_c + \alpha \cdot T_t + \frac{\bar{d} \cdot C_s}{1 + n}$$

Which corresponds to the driver costs of Situation B in the SWP model. It means that the driver is paying only his portion of the operating costs, following the carpooling philosophy conditions.

For the users of carpooling, the costs (Z_{uCP}) are formulated as:

$$Z_{uCP} = \alpha \cdot T_t + g \cdot (1 + \gamma) = \alpha \cdot T_t + G$$

That can be expressed alternatively as:

$$Z_{uCP} = \alpha \cdot T_t + \frac{\bar{d} \cdot C_s}{1 + n} \cdot (1 + \gamma)$$

It is observed that, if the g has the fair price, the Z_{uCP} have the same formulation as Z_{uB_SWP} but adding the commission γ to the kilometric costs.

Hence, if $\gamma = 0$ and $g = \frac{\bar{d} \cdot C_s}{1 + n}$, the formulation for CP model is the same as for SWP model in Situation B.

5.5. CARSHARING MODEL, CS

The particularity of this model, is that it considers the driver of a carsharing service as a user, not the owner. The vehicle fleet owner is now a company.

The formulation of this model is considered different from the others, and new hypotheses are introduced because of this.

5.5.1. HYPOTHESES

The driver is now another user that shares the costs with the rest of passengers. To simplify it, all the users will pay the same amount for variable costs, however, only one of them (probably the driver), has paid the subscription fee.

The fact that the driver becomes a user, induces a change on the Fixed Costs, and the driver does not pay them, but the company does because is the new owner of the fleet. That is why even the driver has to pay to the company for the service, as the users do in other models.

Nowadays, the carsharing companies are using electric vehicles. For this reason, the combustible costs disappear. The fact is that some companies have conventional vehicles too, and they pay the combustible charges. However, to estimate the costs, the study takes into account the rates for the electric vehicles, not others.

To stimulate the use of small and electric vehicles, it is considered that the used vehicles are the simplest ones within the company chances, and that they use electric or hybrid energy.

Usually it is not possible to park a carsharing vehicle in private spots²⁸, so the parking costs are null due to the fact that the vehicles must be parked in free-parking public spots within the area of service of the carsharing company.

Although the parking costs disappear, the users must pay the tolls and the fines. To simplify the kilometric price of this costs, the formulation conserves the cost per kilometer obtained in the last models even though the users of carsharing are not driving this yearly distance \bar{D} .

It is also to consider that the users do not pay a monthly fee, as many companies enforce, but a subscription fee. It simplifies the estimations, because the companies propose many different monthly fees depending on the vehicles and plans used.

The model considers two situations: when the driver is a new user and when it is not the first time that uses the service.

5.5.2. VARIABLE COSTS

On one hand, the Costs of Service and the Parking Costs are not introduced in the present model, as explained before. On the other hand, the model introduces a kilometric and a time-dependent cost factors, resulting:

²⁸ Information obtained from the company policies of Car2go (www.car2go.com).

$$V_c = \left\{ \frac{\left[\frac{(C_{tolls} + F_i)}{D} + G_{km} \right] \cdot \bar{d} + G_h \cdot T_v}{1 + n} \right\} + \alpha \cdot Tt$$

Where:

G_{km} is the kilometric extra cost paid to the company.

G_h is the time cost paid to the company and related to the in-vehicle time.

In Table 17 there is an estimation of the different hourly and kilometric rates of different representative carsharing companies. It is also introduced the subscription fee, G_0 , that affects the driver generalized costs as it is explained in the next section.

	Car2Go	Avancar	Bluemove	Bluemove for new users
Go [€]	9	0	0	0
Gh [€/h]	12.6	5	5.1	4
Gkm [€/km]*	0.29	0.25	0**	0**
* In the case of Car2Go, Gkm is applied after 50 km.				
** The electric vehicles do not pay the Gkm.				

TABLE. 17. G_0, G_h, G_{km} applied by different companies, taking into account the CS model hypotheses.

It is to consider that Car2Go has not implanted its services yet in Barcelona. However, the table introduces its rates because it is one of the most representative carsharing companies in the world, and it proposes a subscription fee, which is interesting for this model.

The variables in green are the ones that are chosen for contributing to the model. It should be clarified that the G_h for Bluemove is a mean of the hourly rates for electric cars implanted for the users without monthly plans, it is, without fixed fees, as can be seen in the Table 29 of the Annex 1. The mean is done between the “Welcome Blue”, which is applied for the first 3 months of use to the new users, and the “Non-fee Blue”, for those users who have exceeded the 3 months of use. The reason of using this mean rate is that the model calculates the costs for new users but also to standard users for which is very inaccurate to predict if they have exceeded this 3 months or not. For new users the rate of Bluemove is shown in the last column of Table 17.

With the information of Table 17 it is computed the Table 18, that shows the estimations of the rates and fees adopted in the model both for new users and standard users.

	G0 [€]	Gh [€/h]	Gkm [€/km]	(d<50 km) Gh (d>50 km) [€/km]
New users	9	4.5	0.25	0.29
Standard users	-	5.05	0.25	0.29

TABLE. 18. G_0, G_h, G_{km} estimation for new and standard users.

It is important to remember that this estimations are based on the hypotheses of the model.

5.5.3. GENERALIZED COST FORMULA

There are going to be two different situations: when the driver is a new user, and when the driver is a standard user.

- New User:

Considering the critical situation that the driver is a new user of the service, the initial subscription fee must be paid. In this case, the driver is the one who pays this fee. The resultant formulation results:

$$Z_{dN_CS} = G_0 + V_c$$

Where:

Z_{dN_CS} are the generalized new user driver costs for Carsharing model.

G_0 is the initial fee that a new user of the service must pay.

The rest of users only have to pay the operating costs. The next formula is also available for those drivers who have used the service before and do not have to pay the initial fee.

$$Z_{uN_CS} = V_c$$

Where Z_{uN_CS} are the generalized user costs for Carsharing model when the driver is a new user.

The hourly and kilometric rates applied are those for New Users on Table 15.

- Standard User:

When the driver is not a new user, all the passengers including the driver have the same costs.

$$Z_{dS_CS} = Z_{uS_CS} = V_c$$

Where Z_{dS_CS} and Z_{uS_CS} are the generalized in Carsharing model for Standard Users. As they are coincident, from now on, the study will call them directly Z_{uS_CS} .

The hourly and kilometric rates applied in this situation are those for Standard Users on Table 15.

5.6. PRIVATE TRANSPORT NETWORK AND CONVENTIONAL TAXICABS MODEL, TC

This is the most complicated model. On one hand, the service prices can make changes depending on the demand, and vice versa. On the other hand, the drivers of this mode are professionals and should receive a benefit from their rides. The formulation proposed is a simplification based on Salanova, J.M. (2013).

5.6.1. HYPOTHESES

In this model it is considered that the vehicle was already own by the driver, so he does not need to pay the registration fee, but he has to pay the license. Usually, the vehicle purchase is also

included in the license price²⁹ Even that, the annual taxes are still considered and they should be higher than the ones estimated before because the drivers are professionals and some taxes are applied on their incomes.

In this model it is important to difference two service modes: the private transport system called Uber, and the conventional taxicabs, called taxi.

Each license for taxicabs is related to a concrete driver and vehicle. Nowadays there are 10.523 licenses in the Metropolitan Area of Barcelona, and they are limited since 2013³⁰. Their actual price in the market is around the 150.000 €.

The model considers that the trips are done in workdays between 8:00 and 20:00 hours, and into the Metropolitan Area of Barcelona, in order to use the conventional tariff called T-1³¹.

The taxi market is considered like a dispatching market, similar to the presented in Salanova, J.M. (2013). However, some simplifications are done in this model.

The taxi drivers do not have to wait for their passengers because they start they service as far as they receive a matching notification, considered automatic while the driver is riding, so that there is no need to introduce an advertisement like, for example, in Carpooling model.

The passengers do not have to walk after receiving a matching for their trip, they only have to wait the driver. This is negative in the sense that, if they had the possibility of walking forward their destination, the trip costs would be lower because less taxi service is paid. However, for this study it is enough to consider that the drivers get to the picking-up location where the passengers are waiting. One of the taxi service advantages is that it takes the passenger to their final destination, which coincides with the drop-off location approximately, so the passengers do not have to walk after the ride as well. It is considered that their access time is null.

5.6.2. FIXED COSTS

The present model has some changes in the formulation of the fixed costs. It is introduced the license cost. This formulation is also new in relation with the other models formulation, in the present model it can be established that:

$$l = \frac{\bar{P}_0}{\bar{L}} + \frac{(l_i - \bar{P}_0)}{L_d}$$

Where:

l_i is the total price of the license.

$(l_i - \bar{P}_0)$ is the portion of the license value without considering the purchase price, so it is a kind of registration fee.

L_d is the average number of years that a driver works as a professional in the taxi sector.

l is the annual cost invested in amortize the license costs.

For Uber, the l is still considering the purchase and registration values used in the other models. It means that $(l_i - \bar{P}_0) = \bar{T}_0 = 3.911$ €. And also $L_d = \bar{L}$ because in the case of Uber, although the

²⁹ See advertisements in *Borsa de llicències – Taxi* (<http://taxi.amb.cat/taxista/borsa-de-llicencies>).

³⁰ It is demonstrated with the data of Instituto Nacional de España, INE.

³¹ According to Àrea Metropolitana de Barcelona, AMB (<http://www.amb.cat>).

driver stays more years as a professional, he should change his vehicle every \bar{L} years, so the registration taxes must be paid again. Hence, for Uber it results:

$$l = \frac{\bar{P}_0 + \bar{T}_0}{\bar{L}} = P + T - T_x$$

With the same formulas of P , T and T_x as in the other models but considering a different estimation for \bar{L} .

However, for the Taxi case, the purchase price is maintained, but the license price is estimated with a fix value of $l_i = 150.000$ €. In this case it is assumed that the permanence in the sector for the drivers is $L_d = 24.4$ years, as studied in Transit (2006). During this amount of time, the driver amortizes the price of the license that does not correspond to the vehicle purchase.

In the formulations of l , it is possible to observe that the license price contains the purchase and the registration costs, but not the annual circulation taxes, as established in the hypothesis. This circulation taxes are estimated with a higher value than the previous models for the reasons explained in the hypotheses. According with Transit (2006), it assumes a value of $T_x = 1171$ €/year.

In the Table 19, it is possible to observe the different values for Uber and for Taxi modes. Also there are the maintenance, insurance, and taxes costs used for the TC model.

UBER	l [€/year]	3709.01501
	$P_0 + T_0$ [€]	19682
	L [year]	5.30653015
TAXI	l [€/year]	8473.18709
	l_i [€]	150000
	L [year]	5.30653015
	L_d [year]	24.4
GENERAL	m [€/year]	821
	i [€/year]	303
	T_x [€/year]	1.171

TABLE 19. Estimation of different annual values for the Fixed Costs for the TC model.

Then, the formula for the Fixed Costs result:

$$F_c = \frac{l + \bar{m} + \bar{i} + \bar{T}_x}{\bar{D}}$$

According to Transit (2006), $\bar{D} = 29.375 + 2 \cdot 6 \cdot 221.6 = 32.036$ km, where the first term is the average annual distance of service for a taxi in the region of Barcelona. The second term is

understood as the distance the taxis made twice a day from the origin (the driver's house) to the destination (the center of the city) and vice versa, considering that the drivers live in the periphery and that the mean distance from the center of Barcelona to its periphery is 6 km. This is multiplied by the average number of days, 221.6, that the driver works in a year. This is the new estimation of \bar{D} for the TC model.

Due to this, the average service life also changes to:

$$\bar{L} = \frac{170000}{32036} = 5.3 \text{ years}$$

The interpretation of this is that a taxi driver changes or his vehicle every 5 or 6 years. It is true that many professional drivers exercise this job for years (L_d), but the fact is that the vehicles must be renewed in order to maintain a modern and comfortable fleet adapted to the city context.

5.6.3. VARIABLE COSTS

Considering the costs of service as in the Carpooling model:

$$C_s = (1 + \delta \cdot n) \cdot \bar{C} \cdot \bar{C}_c + \frac{(P_k + C_{tolls} + F_i)}{\bar{D}}$$

The present model sets the formula for variable costs as follows:

$$V_c = \bar{d} \cdot C_s + \alpha \cdot [\eta \cdot (T_a + T_w) + T_v]$$

Where the parameter η represents the matching facility.

5.6.4. DRIVER BENEFIT

5.6.4.1. COST OF THE TRIP (C_T)

In this model, the cost of the trip is not only the operational costs, but also the fixed costs that the professional drivers have to compensate with the income. The costs are not shared because the driver pays them, but he receives an income that serves to compensate them and also to obtain some benefit.

$$C_T = \bar{d} \cdot (F_c + C_s) = \bar{d} \cdot \left(\frac{l + \bar{m} + \bar{i} + \bar{T}_x}{\bar{D}} + C_s \right) = \bar{d} \cdot C_{km}$$

Where C_{km} is the kilometric cost of the trip, differenced from C_s because C_{km} also includes the portion of costs related to the Fixed Cost.

5.6.4.2. DRIVER INCOME

In taxicab or Uber services the prices depend on the demand, the supply, and other factors that increase the level of complexity, as studied in Salanova, J.M. (2013).

The problem for Uber and this kind of private network companies, is that they offer a dynamic price related with the demand in the moment. It means that the tariffs can change instantaneously depending on the demand density.

For estimating the values of the prices for Uber, an average tariff plan is studied in the city of Madrid³², because Uber services are nowadays forbidden in Barcelona. They obtained that the tariffs were:

- 0.1 €/min
- 1.2 €/km
- Minimum price for a trip: 5 €.

Even though, an estimation for prices in Barcelona and other cities can be observed in the Table 32 of the Annex 1. The price per miles should be converted into kilometers for the calculation.

For our estimations, a mean of the values obtained is done. After observing some fees and fares in the official Barcelona taxi web³³, also summarized in the Table 33 of the Annex 1, it is decided that the tariffs will be composed of an initial fee ("baixada de bandera"), and a kilometric fare. There is also a minimum trip price. It is not considered a fare depending on the travel time. In this way, the tariffs for Uber and Taxicabs are unified in the same model formulation.

The Table 20 shows the average values obtained from the last considerations:

	Uber	Taxi
Go [€]	2.1	2.1
Gkm [€/km]	0.92	1.1
Minimum [€]	5	7

TABLE 20. Fees and fares applied by Uber and Taxi in the TC model.

Hence, the income received by the driver is:

- If $I > m$: $I = G_0 + G_{km} \cdot \bar{d}$
- If $I \leq m$: $I = m$

Where m represents the minimum trip price.

5.6.4.3. BENEFIT CONDITION

In this model the drivers are professionals that should get some positive benefits from their trips.

With this condition, the next rule is proposed, taking into account that the drivers have to deal with the costs of the car.

³² Rodriguez, A. (2016)

³³ Tarifas – Taxi, <http://taxi.amb.cat/s/taxista/tarifas-i-taxes.html>.

$$B = I - C_T \geq 0$$

$$B = I - \bar{d} \cdot C_{km} \geq 0$$

That can be also expressed as:

$$I \geq \bar{d} \cdot \left(\frac{l + \bar{m} + \bar{t} + \bar{T}_x}{\bar{D}} + C_s \right)$$

When this condition is not achieved, the benefits are negative. It means that the fares are not adapted to the supply and the demand. Therefore, the prices should be modified. If this measures do not affect, some drivers could think about shifting to other companies or modes. The advantage of Uber is that they modify their tariffs under these situations. However, in taxi market, it is more difficult to modify the fares in real-time.

5.6.5. GENERALIZED COST FORMULA

The formula that this model adopts for the driver costs (Z_{dTC}) is:

$$Z_{dTC} = \bar{d} \cdot F_c + V_c - I$$

That can be developed resulting:

$$Z_{dTC} = \bar{d} \cdot (F_c + C_s) + \alpha \cdot T_t - B - C_T$$

$$Z_{dTC} = \alpha \cdot T_t - B$$

The negative values represent an income to compensate the costs and obtain a benefit.

If $Z_{dTC} < 0$, the driver is using its working time to produce some benefits. If this happens, it is also demonstrated that I serves to compensate the fixed and the variable costs of the trip and even to take some economic profit.

The next formula is used to calculate the user cost of Uber and Taxicabs (Z_{uCT}):

$$Z_{uCT} = \frac{I}{n} + \alpha \cdot T_t$$

It means that I is divided by all the passengers, so each one pays its portion. To the users costs it is also added the time cost.

All the calculations of this model are realized twice, one for the case of Uber, and the other for the Taxi. Both of them use the same formulation, however, the fares and fees are different.

6. ANALYSIS AND RESULTS OF THE MODELS

The functions proposed on the chapter 6 depend on different parameters that the study has simplified for complexity sake. As a result, the measurement errors are lower but the specification errors increase³⁴. For this reason, it is important to do an analysis of the most important parameters and interpret the results.

In this chapter, the values of the selected parameters change in order to observe the variations produced in the results. The software Excel is helpful for obtaining the results and the study utilize it to observe how the models respond to the reality.

For easily computing, new variables have been introduced to the software, but they are just simplifications of the already studied variables:

$F_c = \bar{d} \cdot F_c$ in order to express the fixed costs in € and thus, compare them with the V_c .

$C_{km} = \frac{C_T}{\bar{d}}$ as a kilometric cost for the TC model, to express C_T in €/km.

$I_{km} = \frac{I}{\bar{d}}$ is the kilometric income for the TC model, in order to compare it with with C_{km} .

Some ratios are also introduced for studying their behavior.

In some cases a special notation is used. As an example: Z_{us_CS3} , means “general costs for one user as a Standard situation in CS model with $n = 3$ ”.

6.1. PRIVATE VEHICLE

6.1.1. DISTANCE

6.1.1.1. ANALYSIS OF COSTS WITH \bar{d}

As justified in the Chapter 4, when the \bar{d} is fixed, it will assume a value of 15 km. This variable affects the fixed and variable costs formulations in the models, so it will be analyzed along its range from 0 to 100 km to observe which changes produces on the costs.

The mean annual travelled distance will be considered as 12000 km.

Fixing the \bar{D} , and varying \bar{d} within its range, we obtain the results showed in Figure 10. It is observed that the result is a set of lines with different pendent. The Variable Costs are higher than the Fixed Costs. This is a normal result: the major part of the total cost of a trip is due to the operation costs, this is the Variable Costs. It means that this mode will be attractive; otherwise, the ownership of a vehicle would be too much expensive to make it effective.

³⁴ Explained at Stopher, P. R. and Meyburg, A. H. (1975).

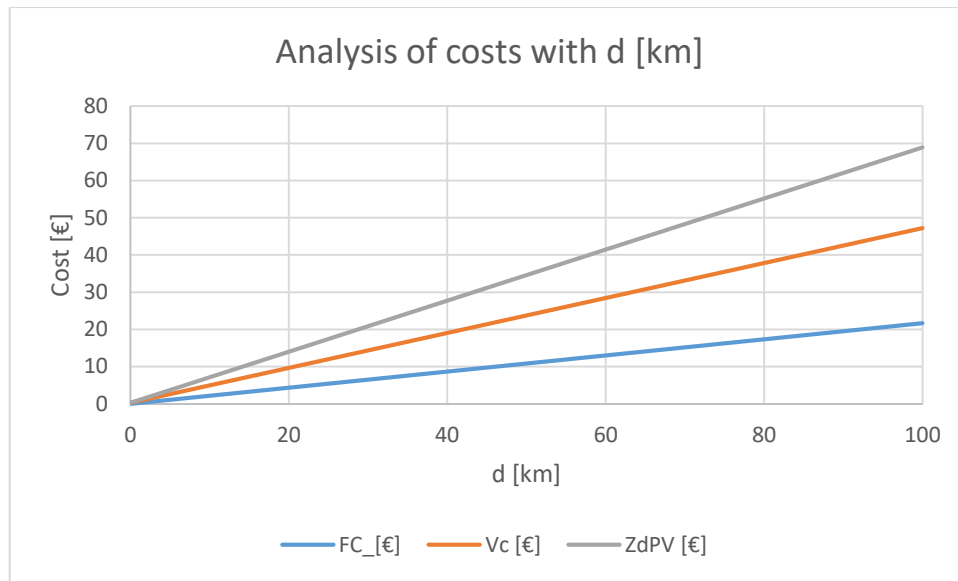


FIGURE 10. Analysis of the fixed, the variable, and the total costs for the driver with the trip distance in the PV model.

The costs are proportional to the travelled distance, and the total cost arises almost the 70 € for trips of 100 km, which looks such a tolerable result in real life. When the trip distance is 0 km, there is yet some cost, as it is shown in the Table 38 of the Annex 2. This is due to the T_a to the vehicle. In the situation that the access to the vehicle is further, hence the access time increases, the initial cost also increases to a point that could make the mode less attractive than others. Remember that, for this study, the limit for the total access distance is considered 700 m. The privilege of the Private Vehicle is that usually this time is lower than in other modes because it is parked near the drivers' place.

What it is also observed from this, is that the initial cost, when the car is not running yet, is produced by the access time. But what happens with the fixed costs? They were defined as the costs that the driver has to pay for the ownership of a car, even if he does not use it. The objective of the study is to determine the cost of a trip for drivers and users in different modes of transport. For this reason, even the Fixed Costs are transformed into kilometric costs, in order to express them depending on the trip distance. It is understood, that if someone owns a private vehicle, is for using it. Otherwise, $\bar{D} = 0$, and all the formulation proposed is not valid. In this situation, an alternative formulation should be applied, for example, maintaining the yearly costs such as the insurance and the taxes, without transforming it into kilometric costs, in order to have a constant cost for all the year.

6.1.1.2. ANALYSIS OF COSTS WITH \bar{D}

The annual travelled distance produces some changes on the cost per kilometer of different variables and also on some annual variables. In this analysis the value of \bar{D} varies within its range from 1000 km up to 26500 km to observe the results. We fix the value of $\bar{d} = 15 \text{ km}$, obtaining the results of Figure 11.

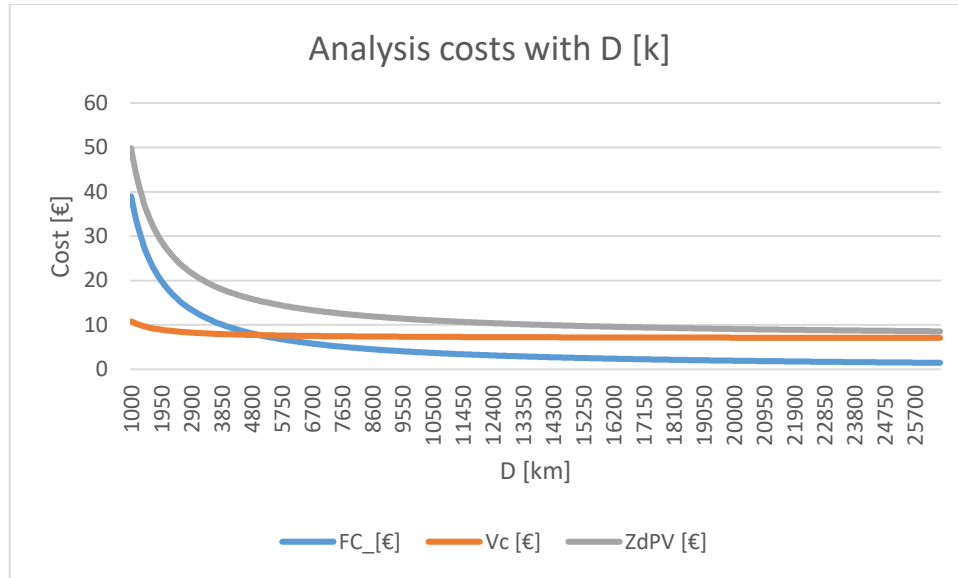


FIGURE 11. Analysis of the fixed, the variable, and the total costs for the driver with annual travelled distance in the PV model.

It is important to observe how the cost of an average trip increases for low values of \bar{D} , it means that the cost of having a PV is higher if the usage of the vehicle is low. In this extreme situation, the F_c are higher, reaching the point to overcome the V_c . The driver is paying too much for a non-used vehicle, so it is an inefficient solution. In this average trip length, the minimum $\bar{D} = 5000 \text{ km}$ is considered to have an adequate usage of the model. Under this value, it is not worth to own a vehicle. It can be observed, in Figure 12, that for less than 5000 km/year, the costs for commuting trips increases up to more of 20 € for less than 20 km trip length, which is an excessive amount for making this attractive.

For higher \bar{D} , the costs converge to a unique value for the current trip, specially the V_c . This is such a good indication for obtaining a specific value of the trip with less influence of \bar{D} .

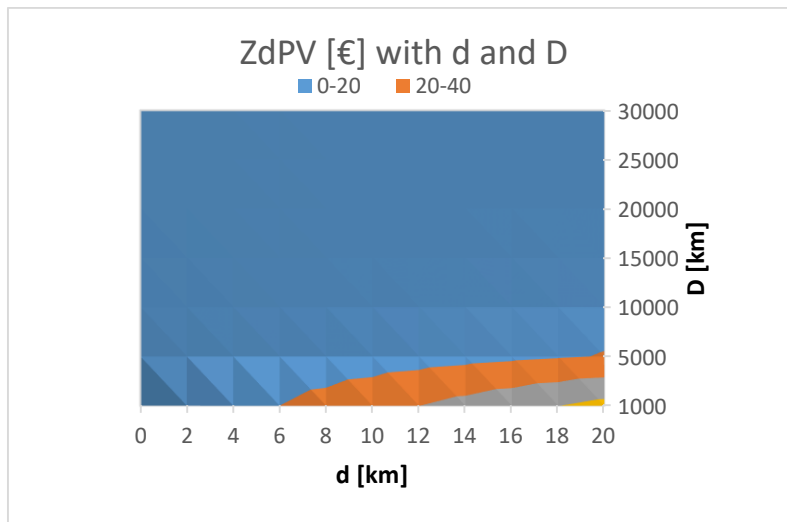


FIGURE 12. Analysis of the costs for the driver with annual travelled distance and trip length in the PV model.

6.2. SHARED RIDES FOR FREE

The new characteristic of this model was the introduction of passengers. The first analysis was realized with a different number of passengers, obtaining the same costs for the users. Only there are a few variations with respect to the drivers' costs. This is because, in this model, the introduction of passengers in the vehicle only causes a little variation in the combustible consumption that is almost negligible.

The important thing is that the users costs are introduced, so the analysis in this section are focused on this.

6.2.1. ANALYSIS OF COSTS FOR THE USERS AND VALUE OF TIME

The cost for the users of this method is the time cost expressed in monetary values. This produces is a simple regression line with respect to \bar{d} because the T_t is proportional to the trip distance. However, the pendent is related to the VoT, and an analysis is done within a range proposed in chapter 4, from 6 €/h to 22 €/h. It can be observed from the formulations of the model, that the dependence of the costs with the VoT is also linear.

Considering the average mean value for $\bar{D} = 12000 \text{ km}$, it is obtained the Figure 13. This figure is valid for any number of passengers in SFF model. It demonstrates the relation between different VoT and the trip cost for different trip distances. For a specific \bar{d} , it is shown that the trip cost increases if VoT also increase, so they are proportional.

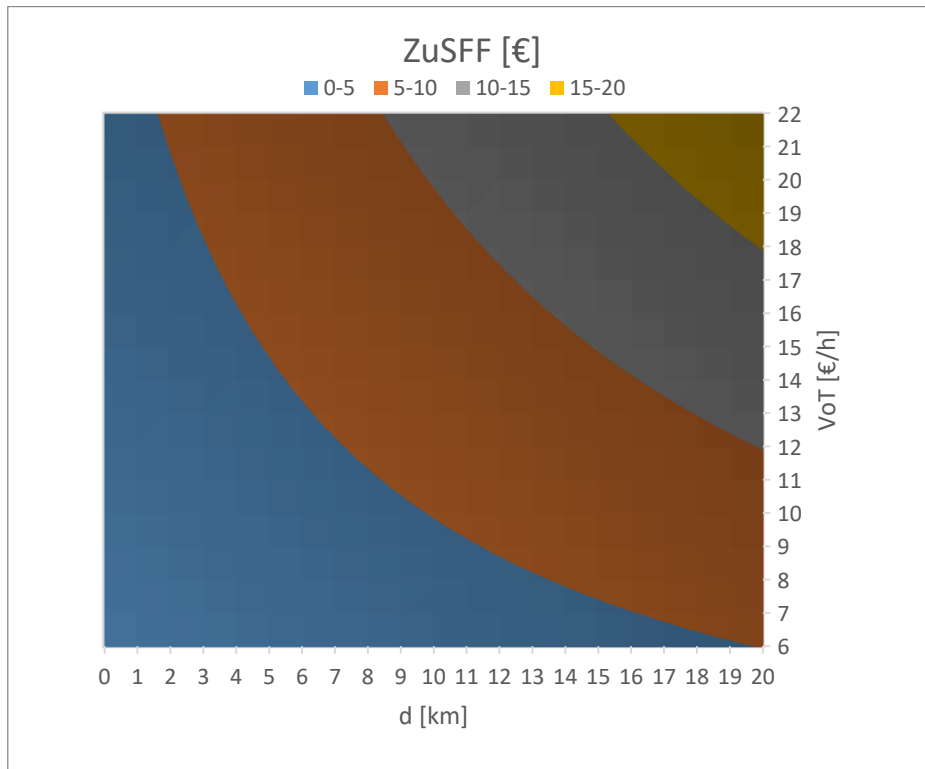


FIGURE 13. Analysis of user costs with VoT and \bar{d} .

6.2.2. COMPARISON OF DRIVER AND USER COST

Now an analysis for comparing the driver and the user costs is done, for an average trip of $\bar{d} = 15 \text{ km}$. For higher values of VoT, the difference of the driver costs with the user costs decreases. It can be considered that high values of VoT conduce to a closer approximation between drivers and users costs, so a bigger ratio, showed in Figure 14.

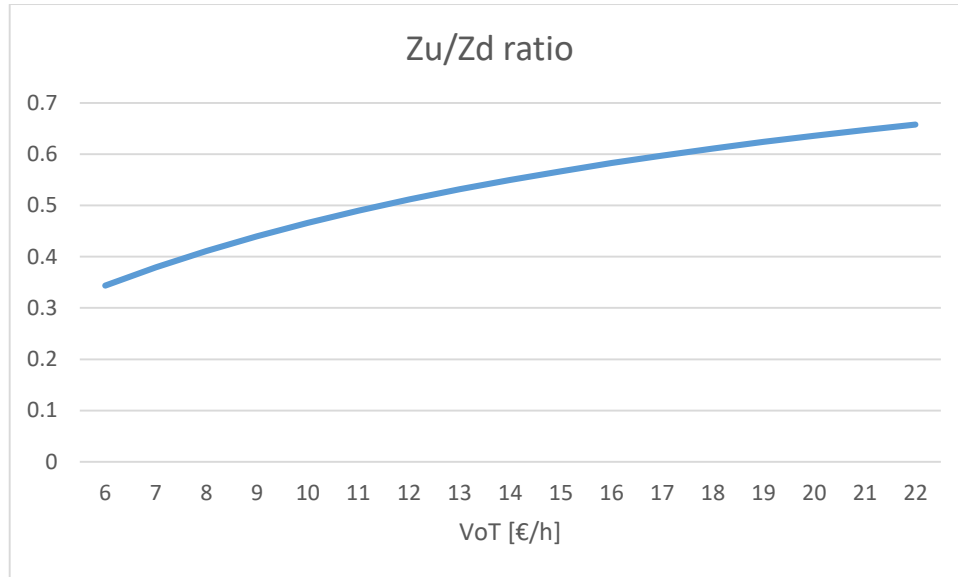


FIGURE 14. Ratio between users and drivers cost in the SFF model depending on the VoT.

The higher the VoT, the higher the costs. One solution of this problem is to reduce the T_t because it is directly associated with VoT. Usually it is difficult to reduce T_v , but in some models, such as CP, CS and TC, it is possible to reduce the T_w and even the T_a with an improvement of the matching and coordination services. It is also true that, for a same level of demand, if the supply increases, the T_w reduces for the users, but usually the supply is limited like the taxicabs with licenses, or the demand varies with the T_w , which is a complex bi-linear problem mentioned before.

6.2.3. COSTS FOR THE DRIVER AND FUEL CONSUMPTION

It has been also proved that, for the SFF model, the number of passengers does not affect too much to the costs. The user costs are the same, and the driver costs do not vary that much with the increment of combustible consumption δ . This coefficient has been analyzed within a range from 0 to 0.125 demonstrating the low grade of dependence of the costs with this parameter. The costs of a specific trip distance are almost the same for different δ , even when $n = 3$. This results are shown in the Figure 38 of the Annex 2.

6.3. SHARED RIDES WITH PAYMENT

In SWP model the most interesting variations are related to the number of passengers, due to the fact that they pay an amount that covers the costs of service between all of them. The more quantity of passengers, the less amount paid per person. This condition is revealed on the results.

6.3.1. COMPARISON OF DRIVER COSTS

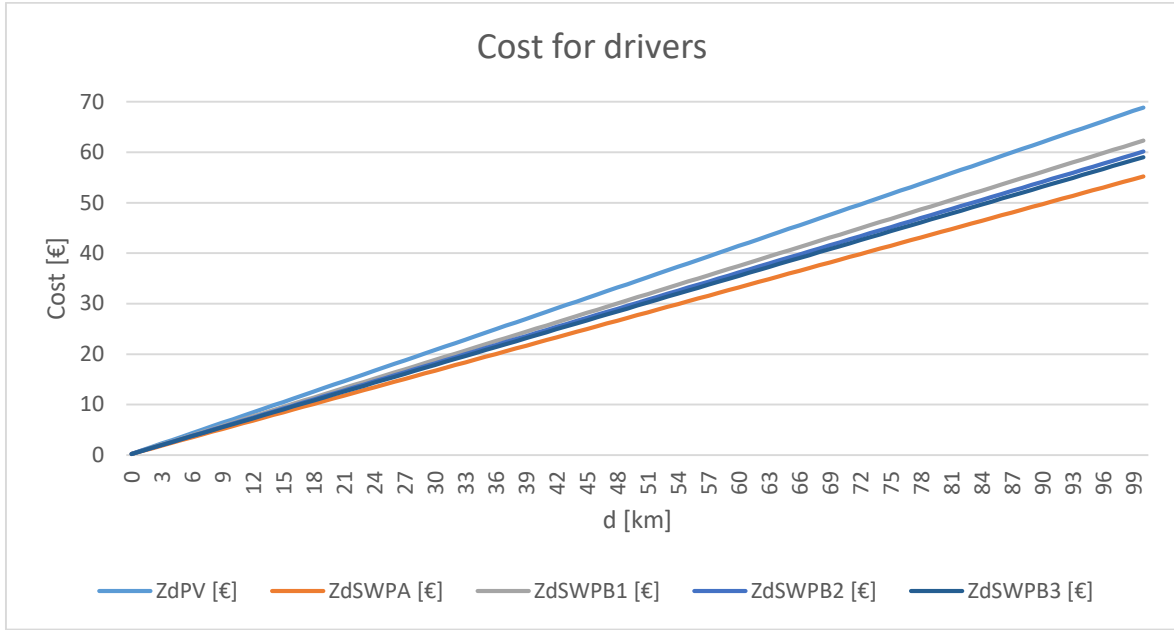


FIGURE 15. Comparison of cost for drivers between PV and SWP models.

In the Figure 15, the costs for drivers with different conditions is compared. The Z_{dPV} corresponds to the case of $n = 0$ passengers. The other notations make reference to the situation of SWP model and the number of passengers. For example Z_{dSWPB2} means driver cost for SWP model in Situation B with $n = 2$ passengers.

It is observed that the highest costs are for Z_{dPV} , because in this mode the drivers pay the full trip as they travel by themselves. What results on the other situations is that, logically, the most economic conditions for the driver is when he does not pay the C_s , which is the case of Z_{dSWPAi} , $\forall i = 1,2,3$, represented by Z_{dSWPA} . For Situation A, it is also observed that the driver costs do not depend on n , as the only dependence with that from the previous formulation was the increment of combustible (because of load) in the C_s , and in the present situation the users are the ones who pay it

Comparing the Situation B lines, it is observed a higher cost for $n = 1$ than for $n = 2$, but for 2 and 3 passengers the lines are very similar. It coincides with the obvious fact that the costs are lower when divided by a higher n , and that they converge as n increases.

6.3.2. COMPARISON OF USER COSTS

Before applying the model, the logic make us think that the users costs are higher in Situation A than in Situation B. The Figure 16 bears out this fact.

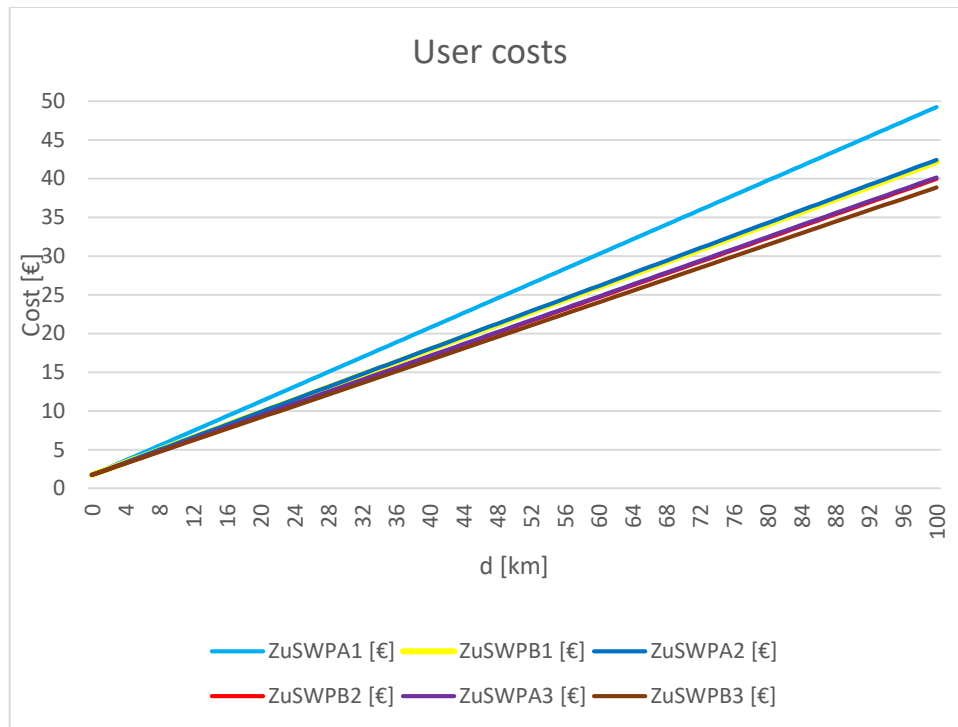


FIGURE 16. Comparison of cost for users in Situation A or B and with $n = 1$, $n = 2$ and $n = 3$.

It also demonstrates that the user costs are lower when a higher number of passengers is introduced. Another important observation is that the user costs when there is one passenger in Situation B, are almost the same as the costs when there are 2 passengers in Situation A. As the driver does not pay the C_s in Situation A, they are divided by the 2 passengers, costing almost the same that when there is just one passenger sharing this costs with the driver in Situation B. Furthermore, with higher accuracy, the user costs are lower in Situation B than A, even with one passenger in Situation B, it is more economic than 2 passengers in Situation A, as shown in the Table 35 of the Annex 2.

6.3.3. COMPARISON OF DRIVER COSTS FOR SWP AND PV MODELS

To obtain the results of this section it has been introduced the ratio between the costs for drivers in SWP related to the costs of the drivers in PV model. The results in Figure 17 show that all the driver costs start at the same value when $\vec{d} = 0 \text{ km}$, because there is only the cost of time. Then, the ratios start to converge to different values depending on the conditions, but all of them located between 0.8 and 0.91 approximately.

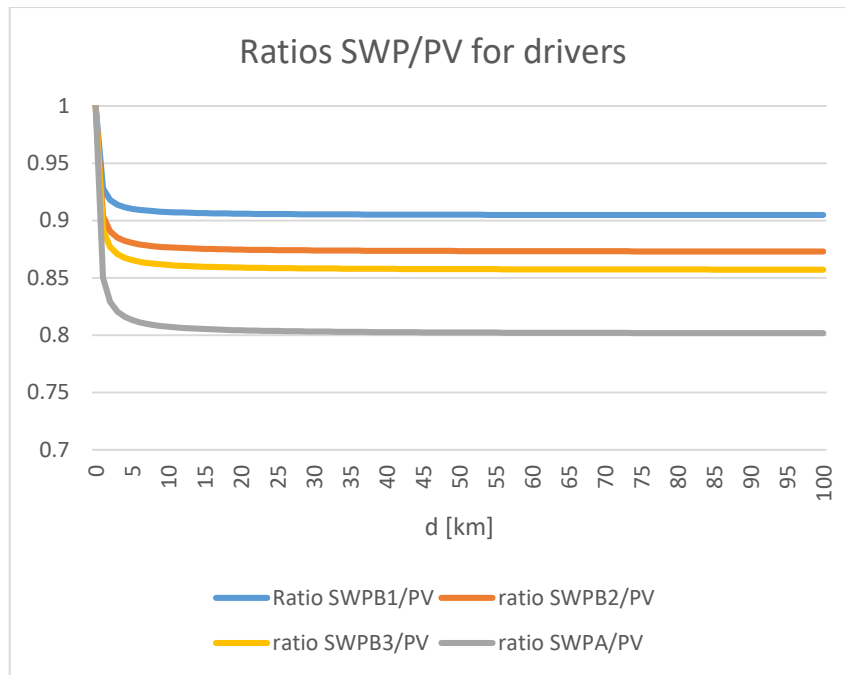


FIGURE 17. Comparison of cost for drivers in Situation A or B and with $n = 1$, $n = 2$ and $n = 3$.

The ratio for Situation A is lower and converges to 0.8, this is a low value comparing to Situation B, because in A the users assume a huge part of the costs of service. However, it is observed how in situation B, where the driver shares the costs in a real way, the rates are higher. When n increases in B, obviously, the driver has to pay less, so the ratios become lower converging to 0.85 as n rises. At this point, the drivers are saving the 15% of the costs if they had chosen to travel alone.

6.3.4. ANALYSIS OF DRIVER COSTS, USER COSTS AND NUMBER OF PASSENGERS

This analysis conduces to observe when a passenger is paying more than the driver in SWP model, and in which moment the driver pays more than a passenger. For this, the situations are studied separately, and then all the ratios are compared.



FIGURE 18. Comparison of cost for users and drivers for SWP model in Situation A, with $n = 1$, $n = 2$ and $n = 3$.

In the Figure 18, it can be observed that for short trips of less than 10 km, approximately, the costs for the users are higher than for the driver. This is because of the access time, which usually is higher for users as commented in the last chapters. It is obvious that as the trip length increases, the cost for the users become lower if the number of passengers is higher. This is observed when comparing the user costs for ZuSWPA1 and ZuSWPA3, the first one is higher and has a higher slope. This slope tends to be more similar as n increases.

The same occurs in Situation B, as shown in Figure 19. The difference here is that the cost for the driver also decrease with the number of passengers, because the driver is also taken into account in the division of the C_s . For this situation, it is also showed that, focusing only on driver cost or in user cost, the decrease of the slope with n is not very notable.

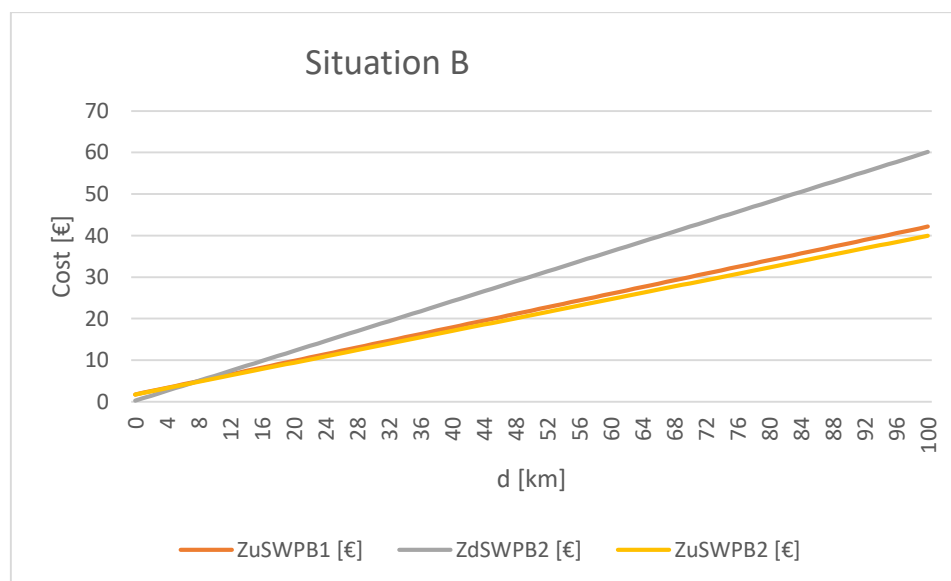


FIGURE 69. Comparison of cost for users and drivers for SWP model in Situation B, with $n = 1$ and $n = 2$.

In order to interpret the results of Figure 18 and Figure 19 with higher accuracy, the next grid is created:

d [km]	rSWPA1	rSWPA2	rSWPA3	rSWPB1	rSWPB2	rSWPB3
0	7.68148279	7.68148279	7.68148279	7.68148279	7.68148279	7.68148279
1	2.84283732	2.75468942	2.72530679	2.52021847	2.56055459	2.58153613
2	2.02156076	1.91845127	1.88408144	1.72900351	1.75140256	1.76312631
3	1.682132	1.57283898	1.53640798	1.40845454	1.4217023	1.42865375
4	1.4966789	1.38400739	1.34645022	1.23487533	1.24271107	1.24682832
5	1.37979958	1.26499882	1.2267319	1.12603902	1.13031724	1.13256714
6	1.29939453	1.183129	1.14437382	1.05141662	1.05318244	1.05411162
7	1.24069458	1.12335969	1.08424806	0.99706624	0.99696463	0.99691114
8	1.19595608	1.07780617	1.03842286	0.95571507	0.95417146	0.95335859
9	1.16072745	1.04193575	1.00233852	0.92319763	0.92050719	0.91909002
10	1.13226778	1.01295762	0.97318757	0.89695641	0.89333221	0.8914228
11	1.10879716	0.98905942	0.94914685	0.87533426	0.87093511	0.86861702
12	1.08910942	0.96901302	0.92898089	0.85721025	0.85215766	0.84949486
13	1.0723582	0.95195664	0.91182279	0.84179898	0.83618798	0.83323052
14	1.05793211	0.93726775	0.89704629	0.82853382	0.82244012	0.8192279
15	1.04537847	0.9244854	0.88418771	0.81699565	0.81048056	0.8070459
16	1.03435492	0.91326104	0.87289641	0.80686784	0.79998168	0.79635111
17	1.02459781	0.90332618	0.8629023	0.79790668	0.79069128	0.78688686
18	1.01590074	0.89447067	0.85399398	0.78992158	0.78241207	0.77845232
19	1.00809987	0.88652768	0.84600362	0.78276129	0.77498747	0.77088812
20	1.00106346	0.87936308	0.83879629	0.77630429	0.76829165	0.76406615
21	0.99468438	0.8728678	0.83226227	0.77045182	0.76222233	0.75788227
22	0.98887464	0.86695222	0.82631141	0.76512278	0.75669552	0.75225097

TABLE 21. Analysis of Z_u/Z_d ratio in SWP model, with n and \bar{d} until 22 km.

The grid of Table 21 shows how many times the user is paying with respect to the driver in SWP model. The most colored values are those that exceed the unity, so those cases where the user is paying more than the driver. The other colored values are when the user pays more than the 90 % of the cost of the driver but less than the cost the driver is paying. The difference observed between the situations is that in B, the n has less influence on the costs than \bar{d} . However, for Situation A, the increment of n produces an earlier decrement of the rates with distance, so it depends more on the number of passengers. With this table it is also possible to analyze, with

more accuracy than with the figures, in which distance the user starts to pay less than the driver, which seems to be the fair condition.

6.4. CARPOOLING

In this model a fixed trip cost for the user was introduced: g . Recalling the formulation from Chapter 5, the drivers get an income from these user payments. According to the Carpooling philosophy, the benefits obtained from the driver must be 0, in order to spend this income for paying the operational costs.

6.4.1. ANALYSIS OF DRIVER BENEFIT WITH g , \bar{d} AND n

In the formulation, an optimization for g was done in order to achieve the condition of $B = 0$. However, it was explained that drivers do not know the demand of their trip beforehand, so they propose a g according to the company recommendations³⁵.

In the Figure 20 we can observe how different values of g have an effect on the driver benefits when there is only one passenger. The yellow line shows the values of g that produce a zero-benefit depending on the length of the trip. It is logical that g has to increase with the trip length, in order to palliate the trip costs.

The points located over the yellow line represent positive benefits for the driver, that even could make negative the driver generalized costs, which means that the driver is earning money from his trips, and this is not the carpooling philosophy because the drivers are not professionals. The points under this line represent negative benefits for the driver, which means the driver is not compensating the trip costs with the income, so he must pay a bigger portion of it.

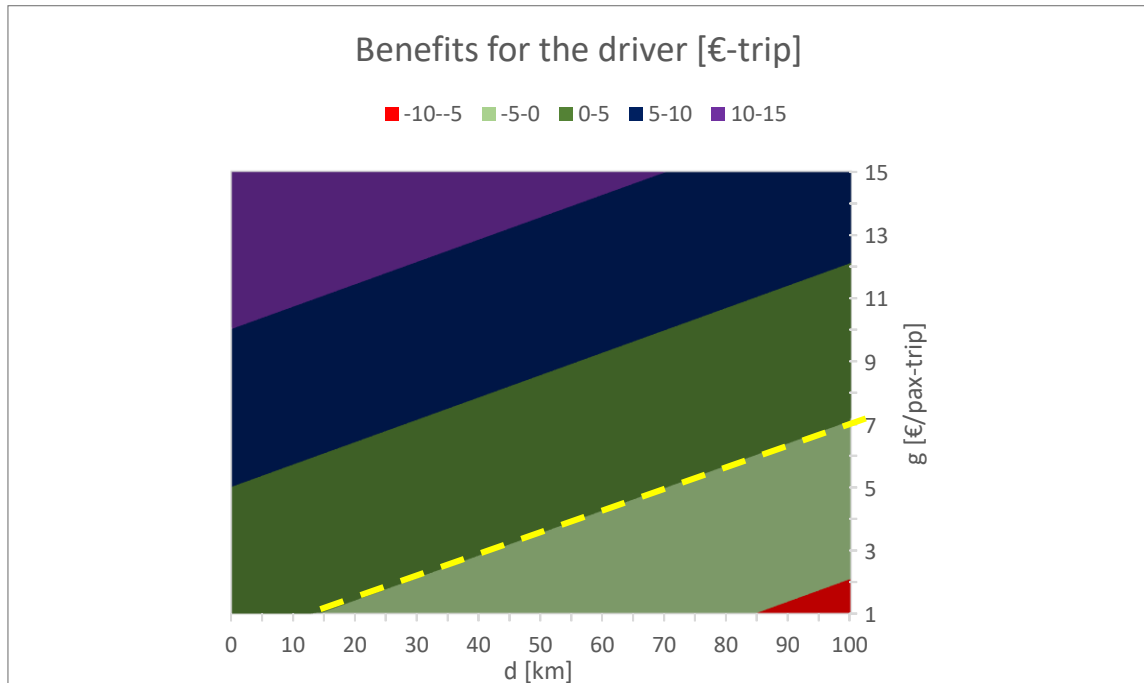


FIGURE 20. Analysis of driver benefits in the CP model with g and \bar{d} , for $n = 1$.

³⁵ This is how it works when drivers advertise their trips in BlaBlaCar.

In the Figure 21 there is an analysis of the driver benefits, varying g and the number of passengers, for a specific trip length of $\bar{d} = 15 \text{ km}$. The yellow curve represents the condition of zero-benefit. It is observed that, for example, for $\bar{d} = 15 \text{ km}$ and one passenger, the fair g is about 1.05 €/pax. If the driver proposes this price but, at the end there are more passengers, he will obtain some benefit. On one hand, the points located at the right side of the yellow line are the ones that make the driver obtain some benefit. On the other hand, the points located at the left produce negative benefits for the driver, with the consequences explained above.

In the left extreme of the Figure 21, it is observed that the loss for low prices is higher for 3 passengers than for 1. This is because the driver is paying a bigger amount related to the quantity of passengers that are not paying a proper fare. If this quantity is higher, the driver should pay more.

It is important to remark that, if $n = 0$, the conditions of sharing cannot be used. Usually, when in SFF and SWP models there are no passengers, the costs coincide with the PV costs. In this model they would be the same if the waiting time and the condition of the stopovers had not been considered. For this reason, if in this model $n = 0$, the formulation proposed is not valid and it must retake the one proposed for the PV model.

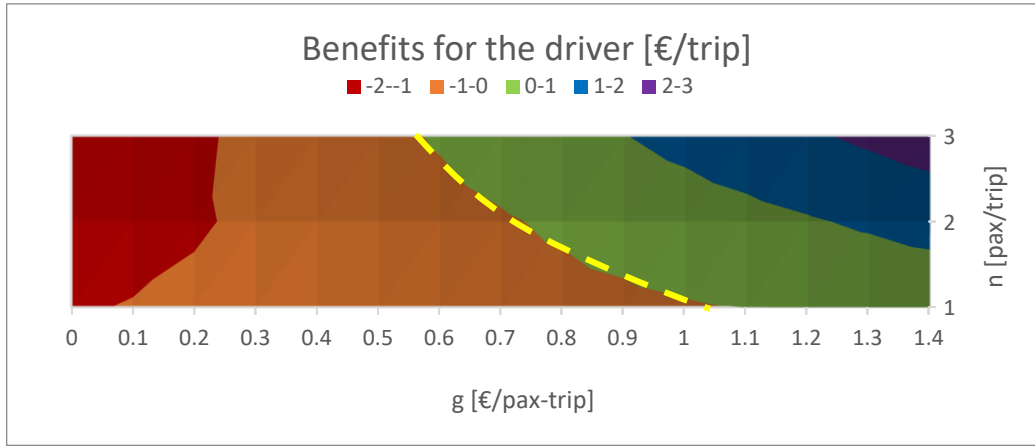


FIGURE 21. Analysis of driver benefits in the CP model with g and n , for $\bar{d} = 15 \text{ km}$.

As far as the drivers do not know the demand of their trip, they should propose a fair price for the users. This price should be decided in order not take too much profit, but also high enough for not producing loss.

For the later comparison of costs depending on the models, in the case of CP, the prices applied for the users are those calculated with the optimization formula that comply the zero-profit condition. It is calculated as if it was known beforehand how many passengers will be in the trip.

6.4.2. COMPARISON OF DRIVER AND USER COSTS

A particularity to remember of this model is that an extra waiting time was added because of the possibility of picking-up the passengers in the stopovers. The results Figure 22 show that, for low \bar{d} , the cost for the driver is higher when higher is the number of passengers. This is due to the fact of the waiting time. However, the step of the lines is higher for little n because the costs per kilometer paid by the driver are higher. For this reason, there is a point where the costs for the driver are lower when there are more passengers, as can be seen with ZdCP3 when $\bar{d} = 100 \text{ km}$. Very similar results are shown in the Figure 39 of the Annex 2.

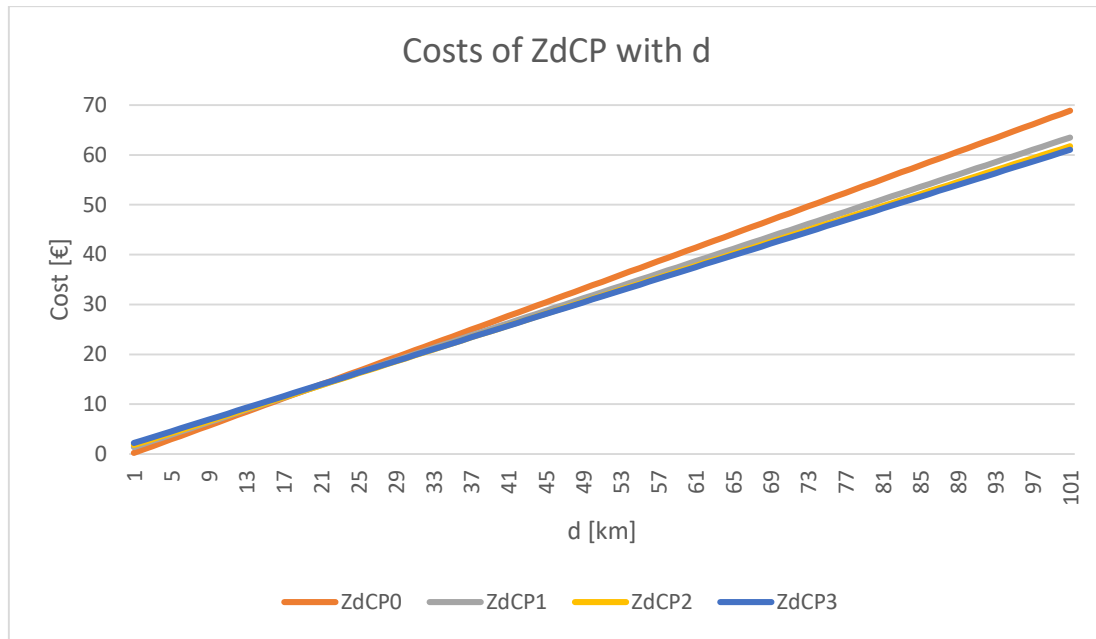


FIGURE 22. Comparison of driver costs in CP model, for $n = 1, 2$ and 3 .

To compare the driver and user costs, the Figure 23 shows the ratio $\frac{Z_u}{Z_d}$ for different length trips and passengers. It is observed that, for short trips with about less than 6 km length, the users costs are higher than the drivers'. This is because of the access time, which is higher for the users with respect to the drivers. As the length trip increases, the ratios converge to 0.7 approximately, it means that the users trip cost tend to be the 70 % of the drivers cost, in CP model. The value of the ratios are very similar independently of the number of passengers.

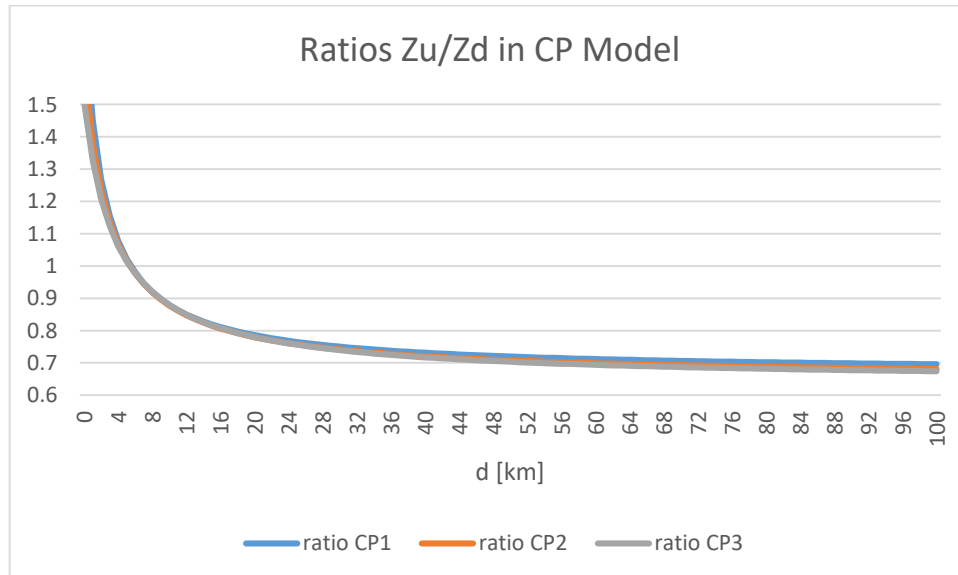


FIGURE 23. Ratios Z_u/Z_d in CP model, for $n = 1, 2$ and 3 .

6.4.3. COMPARISON OF DRIVER COSTS FOR CP AND PV MODELS

To compare the driver costs in the CP model with the PV model, their ratio has been studied, considering that some passengers are sharing the trip in the case of CP model. The results of Figure 24 show that for trips of less than 20 km, approximately, the drivers costs are much higher for CP model than for PV. The reason of this, again, is the access and waiting time, which are higher in the CP model. As the length of the trip is longer, achieving the long-tip values, the ratios tend to be between 0.85 and 0.95 with respect to the PV.

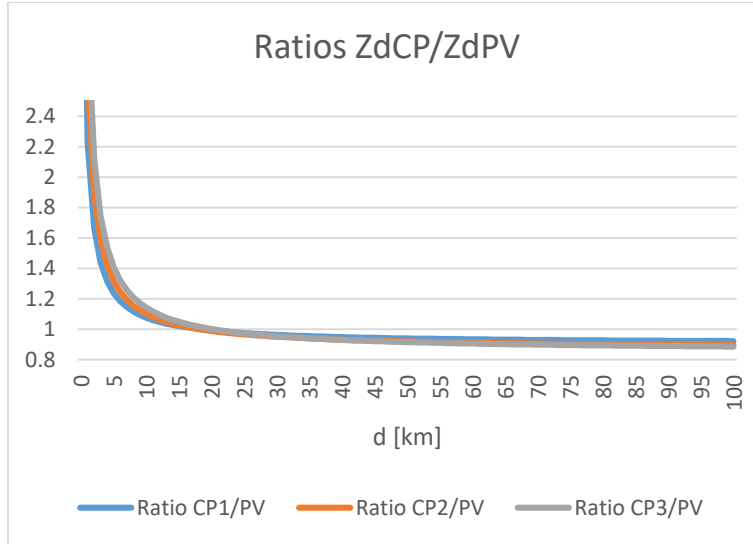


FIGURE 24. Ratios of driver costs in CP model with respect to the PV model, for $n = 1, 2$ and 3 .

6.5. CARSHARING

In this model, the drivers do not own the vehicles, so the drivers are converted into users, too. In this model, if $n = 0$, the cost for the driver is not the same as in PV model, as occurred in the other models. The formulation used for this model is much more different, compared with the "driver-vehicle ownership" models.

In addition, as it was explained before, there are two situations to consider: the new user and the standard user.

6.5.1. COMPARISON OF DRIVER AND USER COSTS

First, to remember the difference between the situations, it is useful to observe the Figure 25. As we can see, it represents the cost for the drivers depending on their situation. If it is the first time they use the service, they must pay the initial fee, and that is the reason why the blue line starts with higher costs than the red line, corresponding respectively to new and standard drivers. It is important to note that $Z_{dS,CS} = Z_{uS,CS}$. Due to this, considering the situation Standard, both drivers and passengers are called users, because they have exactly the same costs.

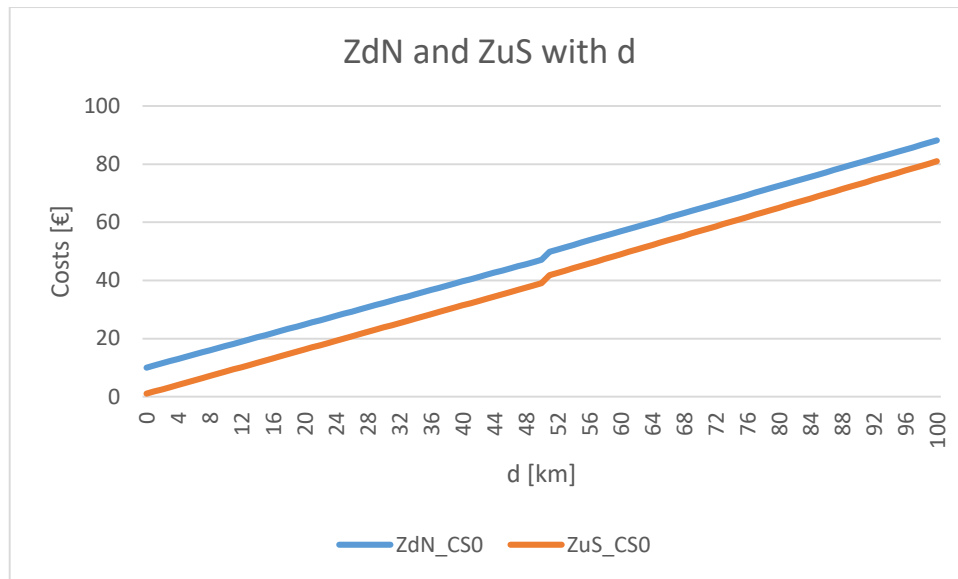


FIGURE 25. Costs for drivers in CS model, depending on \bar{d} and on their situation as News or Standards, for $n = 0$.

More results related to the driver and user costs for New situation, respectively, can be found in Figure 40 and Figure 41 of Annex 2. As in other models, it is observed how the costs become lower if there are more passengers. It is also to observe that all the lines start from the same point, the subscription fee for the case of the drivers. They also start from the same point but with a lower value related to the access time in the case of the users.

In the figures obtained from the application of this model, it is observed that at about $\bar{d} = 50 \text{ km}$, a little step is showed. This is because the kilometric tariff changes when the length of the trip exceeds this amount of km.

In this model, the user costs do not never exceed the driver ones. As it has been stated, the driver and user costs are the same for Standard situation. With respect to the New situation, the Figure 26 is studied to see how the user costs are lower than the driver, as he pays an initial fee. Due to this, the result obtained is a curve that raises from a low value to values that exceed the 0.8 and converge to values within a range of 0.81-0.95 depending on the number of passengers. The curve related to ZuN0 seems not having sense, because there are no passengers, but it represents the driver who has already paid the subscription fee but stills paying the new user tariffs within the first 3 months. It is also observed an obvious result: more number of passengers conduce to a lower percentage of the driver cost paid by a user.

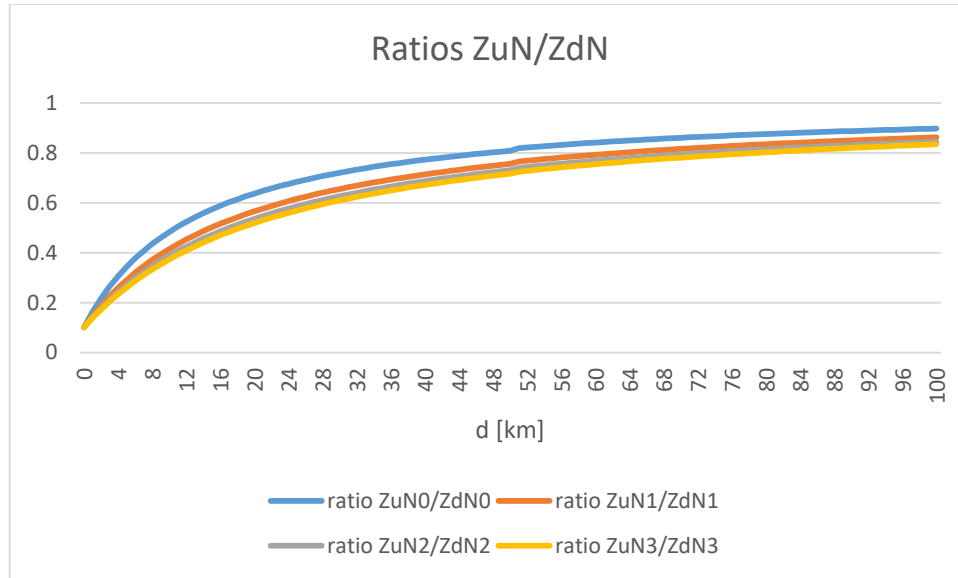


FIGURE 26. Ratios Zu/Zd for the New Situation in CS model depending on \bar{d} , for $n = 0, 1, 2$ and 3 .

It is important to remark that the users do not have the same costs in the New user situation than in the Standard one. The reason of this is that the tariffs applied are different.

The results for the users and drivers in the Standard situation, reveal that their costs are the same, as expected from the formulation. It is observed in the Figure 41 of the Annex 2. As observed in other situations, when there are more passengers, the trip costs are reduced for each one.

6.5.2. ANALYSIS OF DRIVER OR USER COST WITH G_{km} AND G_h

The kilometric and hourly rates have a notable effect on the decision for a user of getting his private vehicle or use a Carsharing service. An analysis is done for a specific $\bar{d} = 6 \text{ km}$, which is considered a urban trip with a long length, for different values of G_{km} and G_h . The results are shown in Table 22 that corresponds to the driver riding alone. The cells on green indicate the combinations that produce a cost lower than for a driver in PV³⁶. It is observed that for the estimations of the rates in our application case ($G_{km} = 0.25 \text{ €/km}$ and $G_h = 5.05 \text{ €/h}$), it is not worth to take the Carsharing service alone. There are two possible solutions:

- Sharing the trip with more users. This is an optimum chance considering the objective of enhancing ridesharing. Analyzing the results of Table 36 and Table 37 of Annex 2, it is noted that, even for a higher $G_h = 6 \text{ €/h}$, the cost of CS with $n = 2$ are lower than for PV. Even with worse rates combinations.
- Decreasing the rates. This only depends on the company policies, and it is very difficult to change it because they have to afford the fleet expenses, as they are the owners. However, it is observed that for combinations with lower rates than the estimated in our study, it is possible to have better costs of CS with respect to PV, even with the driver riding alone. With more government subventions and publicity incomes, it would be more easy to achieve it.

³⁶ It can be observed in Table 34 of the Annex 2.

ZuS0 [€]	Gh [€/h]								
		0	2	4	6	8	10	12	14
Gkm [€/km]	0	3.067	3.467	3.867	4.267	4.667	5.067	5.467	5.867
	0.05	3.367	3.767	4.167	4.567	4.967	5.367	5.767	6.167
	0.1	3.667	4.067	4.467	4.867	5.267	5.667	6.067	6.467
	0.15	3.967	4.367	4.767	5.167	5.567	5.967	6.367	6.767
	0.2	4.267	4.667	5.067	5.467	5.867	6.267	6.667	7.067
	0.25	4.567	4.967	5.367	5.767	6.167	6.567	6.967	7.367
	0.3	4.867	5.267	5.667	6.067	6.467	6.867	7.267	7.667

TABLE 22. Analysis of driver or user costs in Standard situation for CS model, with G_h and G_{km} for $\bar{d} = 6$ km and $n = 0$.

6.6. UBER AND TAXI

The analysis of TC model is the most complex. It is interesting to understand that the demand and the rates are correlated: higher demand is produced by lower tariffs, but it also increases the costs for the drivers, who need to take some benefit. In this study, the demand is not predicted, but an analysis of the costs for drivers and users is done for different tariffs.

Because of the controversy between Uber and Taxis, it is of the interest of this study to analyze their costs for different prices, distances, and passengers. It is important to extract for which tariffs the Taxi is better than Uber for the drivers or for the users.

6.6.1. ANALYSIS OF DRIVER COSTS WITH G_{km} , n , AND \bar{d}

The Table 23 shows an analysis of costs for Uber drivers with different G_{km} and n considering a long urban trip of $\bar{d} = 6$ km. The costs are negative because the drivers are earning money from their trips. It was observed in the last chapter that they compensate their operational and time-dependent costs with their income, and with the objective of taking some economic profit.

ZdUB[€]	n[pax]	Gkm[€/km]						
		0	0.25	0.5	0.75	1	1.25	1.5
	1	-0.444	-0.444	-0.544	-2.044	-3.544	-5.044	-6.544
	2	-0.411	-0.411	-0.511	-2.011	-3.511	-5.011	-6.511
	3	-0.379	-0.379	-0.479	-1.979	-3.479	-4.979	-6.479

TABLE 23. Analysis of costs for Uber drivers in TC model, with n and G_{km} for $\bar{d} = 6$ km.

This table is compared with the Table 24, that has the same conditions but is applied to the Taxi case. The green cells are the ones which, applying the same combination for both models, produces a higher profit for the Taxi drivers than for the Uber drivers. It is observed for $G_{km} < 0.5$ €/km. This is because the high costs per kilometer of the Taxi (C_{km}) drivers have not done

their effect yet. This situation changes for higher length trips, as it can be observed in the Table 38 of the Annex 2, where for $\bar{d} = 15 \text{ km}$, any of the tariffs analyzed makes the Taxi more profitable for the users than Uber. The yellow cells indicate the conditions for having fewer costs than Uber does with the rate estimated in the application ($G_{km} = 0.92 \text{ €/km}$), showed in Table 25. This procedure is repeated for $\bar{d} = 15 \text{ km}$ with the conditions of Table 39 of the Annex 2. As it is observed, the kilometric prices for the Taxi must be higher than 1 €/km to obtain higher profit than with Uber, if it uses the proposed price. In real life, this situation happens: the Taxis obtain higher kilometric benefits than the Uber drivers. However, as we will observe, the user costs are lower for Uber cabs. This produces a shift of the demand to this mode rather than for Taxi that is not studied because it is hard to estimate the demand and how the prices induce an effect on its elasticity.

ZdTX[€]		Gkm[€/km]						
		0	0.25	0.5	0.75	1	1.25	1.5
n [pax]	1	-1.551	-1.551	-1.551	-1.551	-2.651	-4.151	-5.651
	2	-1.519	-1.519	-1.519	-1.519	-2.619	-4.119	-5.619
	3	-1.486	-1.486	-1.486	-1.486	-2.586	-4.086	-5.586

TABLE 24. Analysis of costs for Taxi drivers in TC model, with n and G_{km} for $\bar{d} = 6 \text{ km}$.

Gkm = 0.92 €/km d = 6 km	
n	ZdUB
1	-3.064
2	-3.031
3	-2.999

TABLE 25. Driver costs for Uber drivers in TC model, with different n , for $G_{km} = 0.92 \text{ €/km}$ and $\bar{d} = 6 \text{ km}$.

It is now introduced an analysis of the driver costs with the kilometric prices and the trip length. It is considered the average situation of $n = 2$. The Figures 27 and 28 represent the costs for the drivers depending on the kilometric fares and on the distance. The blue areas represent negative costs, and it means an economic profit for the drivers. In the other hand, the red area represents a real cost for the driver. As professionals, the drivers should not have a positive cost as a result of their trip, so the curve between the blue and the red areas represents the minimum G_{km} to apply. It is observed that the prices for Taxi are higher because they also have higher operational costs. For short distances, in both situations, the fares can be very small because the operational costs are also low.

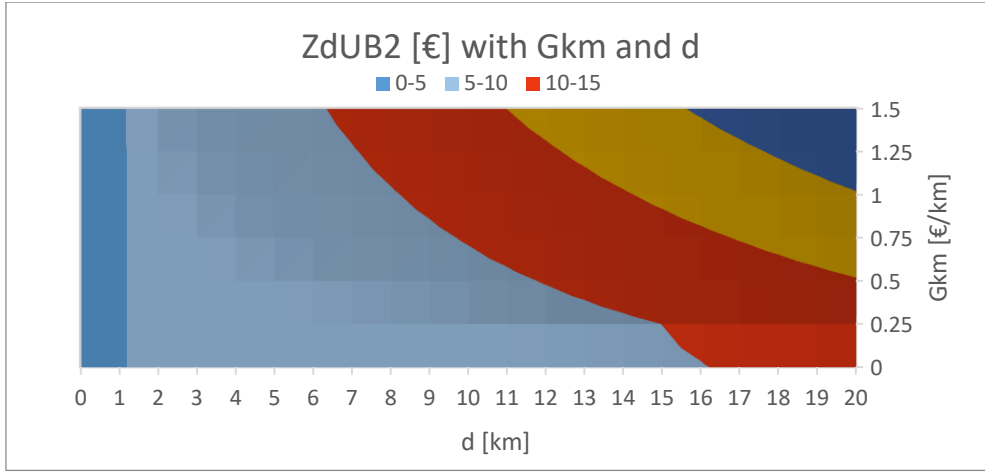


FIGURE 27. Analysis of Uber driver costs with G_{km} and \bar{d} , for $n = 2$.

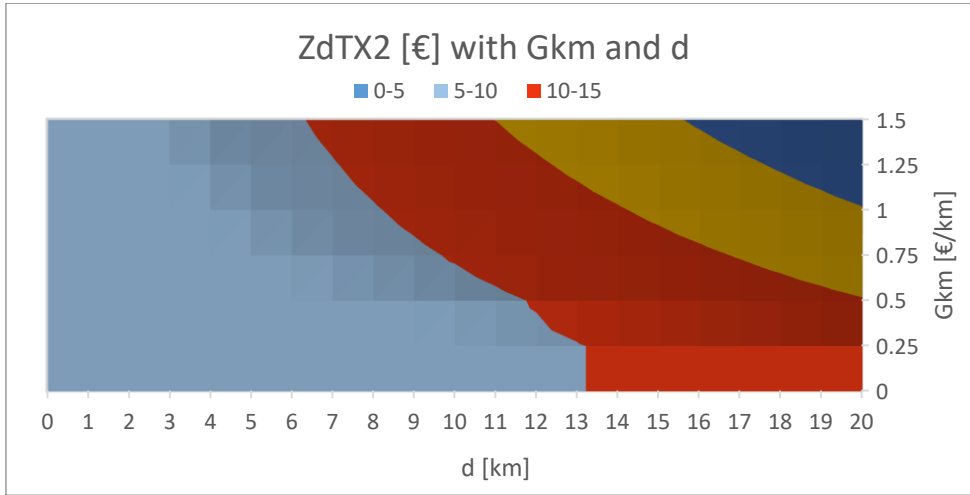


FIGURE 28. Analysis of Taxi driver costs with G_{km} and \bar{d} , for $n = 2$.

6.6.2. ANALYSIS OF USER COSTS WITH G_{km} AND \bar{d}

From the formulation proposed, it is seen that, if the G_{km} is the same for both situations, the costs for the users are almost the same. The only change is when the total prices are low and the minimum fare, which is different for Uber and for Taxi, is applied. This can be observed when the initial slopes of Figure 29 are almost plate. In addition, this figure shows how the costs for Uber are always lower than for Taxi according to the prices estimated for this study.

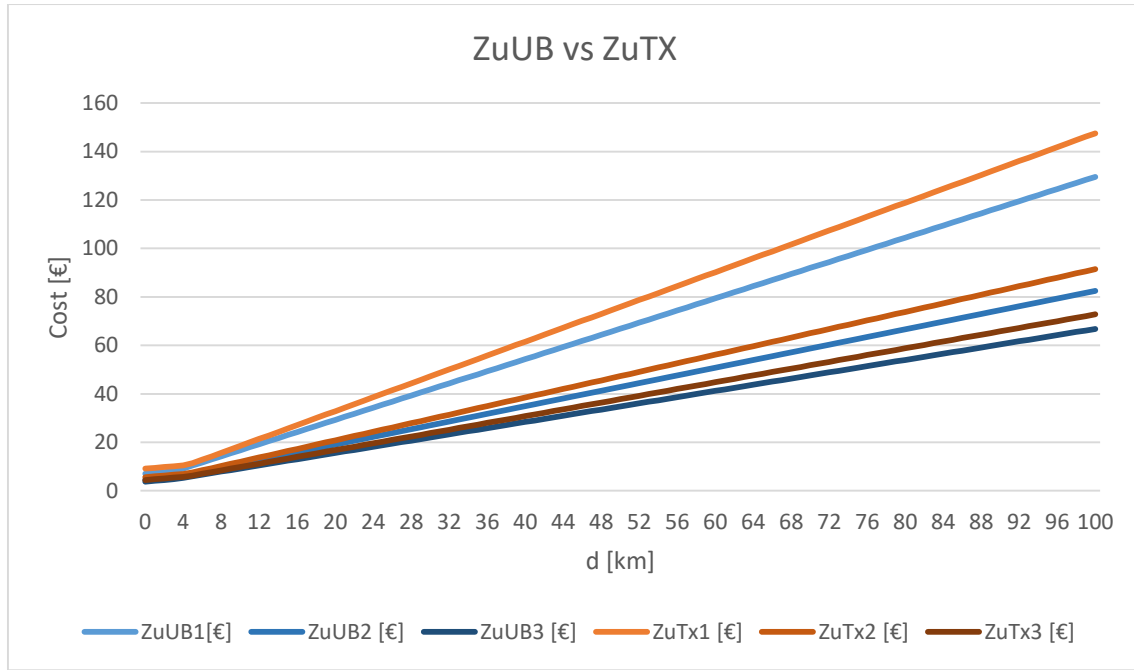


FIGURE 29. Comparison of user costs for TC model, varying \bar{d} and for $n = 1, 2$ and 3 .

If the prices change, the user costs behave like in Figures 30 and 31. In this figures it is shown how the costs are lower in Uber for low fares, but they become similar with the distance and the prices. The red and yellow areas are almost the same, and correspond to high values of G_{km} and for longer trips. It is also observed that for low distances, the costs are very similar independently of G_{km} , this is influenced by the minimum trip cost applied in this mode.

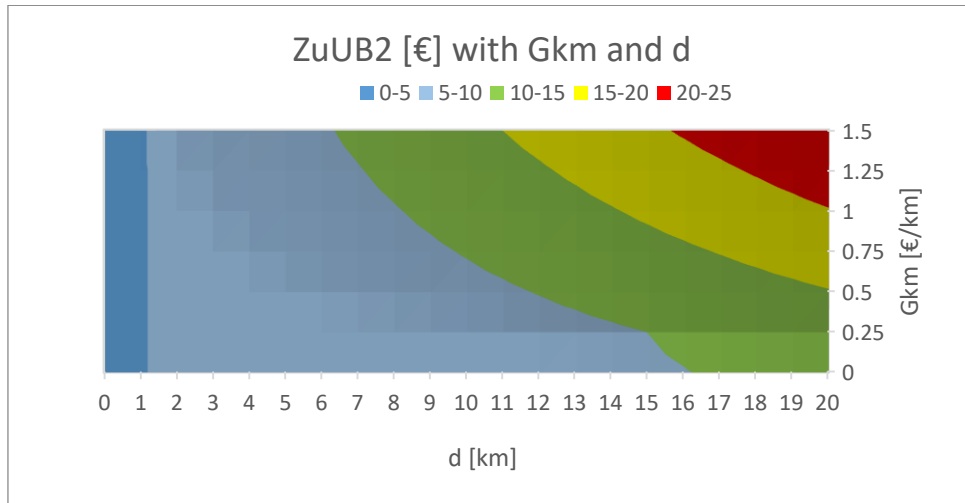


FIGURE 30. Analysis of Uber user costs with G_{km} and \bar{d} , for $n = 2$.

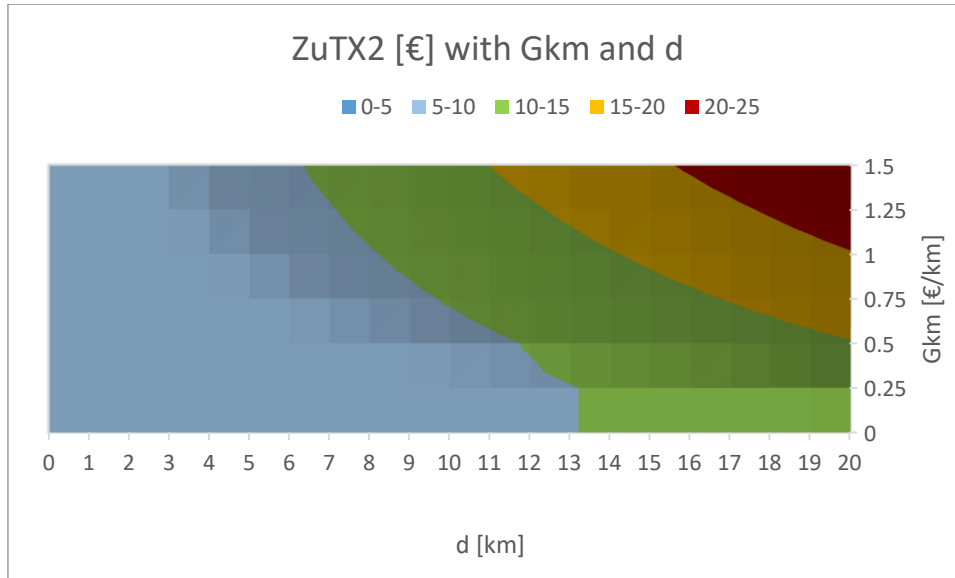


FIGURE 31. Analysis of Taxi user costs with G_{km} and \bar{d} , for $n = 2$.

6.7. COMPARISON AND GRADING OF THE MODELS

It was explained how the lack of information was an inhibitor of ridesharing. With the models adopted, a comparison of the costs depending on the distance is done for the different models and situations.

6.7.1. ANALYSIS AND COMPARATION OF DRIVER COSTS

The Figure 32 shows the driver costs when there is only one passenger, with the exception of the PV driver costs (ZdPV), that is also introduced for valuating how expensive it is with relation to the other modes. It is observed that, generally, the ZdSWPA is the most economic chance; however, it is not such an ethical solution to make the passengers pay the full operational costs without taking into account the driver himself for the division of costs, this is not sharing, this is what professional drivers do. For this reason, it should not be considered. Without considering it, it is observed that the most economic option for long inter-urban trips is the CS for Standard users, however, it is true that the companies usually do not allow to exit the city area, and if this occurs extra costs are included, but this is not contemplated in the present study. . The PV costs become the highest ones when the trip becomes longer; this is due to the operational costs that the driver must assume by himself. It is observed that the PV line coincides with the SFF line, of course, the cost for the drivers in this models are very approximated, only the fuel consumption varies and it has been studied that it is not such a influencer factor.

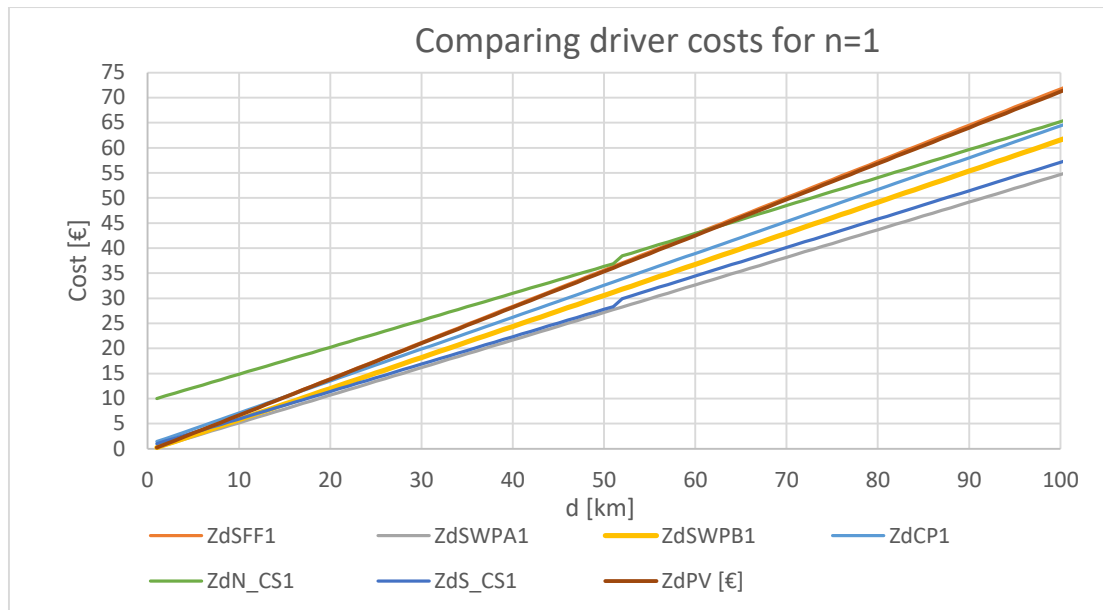


FIGURE 32. Comparison of the different driver costs depending on the model and \bar{d} , for $n = 1$.

In the Table 26, a reticular grid helps to graduate the costs for typical commuter and urban trip lengths, until 22 km, and for one passenger. The green cells represent the most economic options for the drivers, and the red ones the most expensive. It is also introduced the costs for Uber and Taxi, that are negative because they represent economic profits for the drivers.

d (km)	ZdSFF1	ZdSWPA1	ZdSWPB1	ZdCP1	ZdN_CS1	ZdS_CS1	ZdUB1 [€]	ZdTxl [€]
0	0.225	0.225	0.225	1.417	10.019	1.019	-3.064	-3.251
1	0.947	0.775	0.846	2.037	10.557	1.566	-3.341	-3.560
2	1.669	1.324	1.466	2.658	11.094	2.112	-3.618	-3.868
3	2.391	1.874	2.087	3.279	11.631	2.659	-3.896	-4.177
4	3.114	2.424	2.708	3.900	12.169	3.205	-4.173	-4.486
5	3.836	2.974	3.329	4.521	12.706	3.752	-4.450	-4.794
6	4.558	3.524	3.950	5.141	13.243	4.298	-4.727	-5.103
7	5.280	4.074	4.570	5.762	13.781	4.845	-5.005	-5.411
8	6.002	4.623	5.191	6.383	14.318	5.391	-5.282	-5.720
9	6.725	5.173	5.812	7.004	14.855	5.938	-5.559	-6.028
10	7.447	5.723	6.433	7.625	15.393	6.484	-5.836	-6.337
11	8.169	6.273	7.054	8.246	15.930	7.031	-6.114	-6.645
12	8.891	6.823	7.675	8.866	16.467	7.577	-6.391	-6.954
13	9.613	7.372	8.295	9.487	17.005	8.124	-6.668	-7.263
14	10.336	7.922	8.916	10.108	17.542	8.670	-6.946	-7.571
15	11.058	8.472	9.537	10.729	18.079	9.217	-7.223	-7.880
16	11.780	9.022	10.158	11.350	18.617	9.764	-7.500	-8.188
17	12.502	9.572	10.779	11.970	19.154	10.310	-7.777	-8.497
18	13.225	10.122	11.399	12.591	19.692	10.857	-8.055	-8.805
19	13.947	10.671	12.020	13.212	20.229	11.403	-8.332	-9.114
20	14.669	11.221	12.641	13.833	20.766	11.950	-8.609	-9.423

TABLE 26. Grading of the different driver costs depending on the model and \bar{d} , for $n = 1$.

It can be demonstrated that, without taking into account traditional ridesharing such as SFF and SWP, the best way of moving is CS and then CP, rather than PV. This results can be studied with more accuracy in the Figure 33, for urban and inter-urban trips up to 20 km, like the most common distances for commuters.

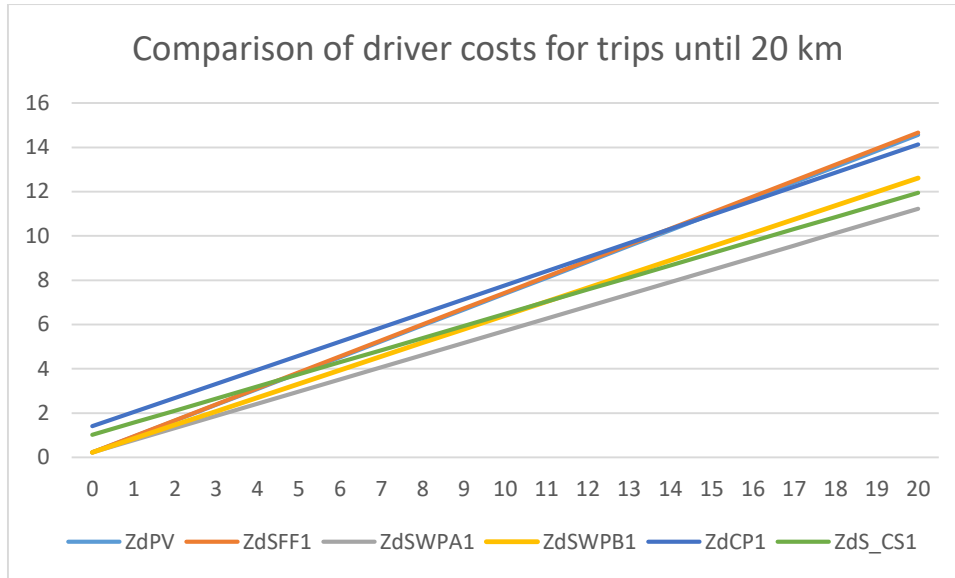


FIGURE 33. Comparison of the different driver costs depending on the model and $\bar{d} \leq 20$ km, for $n = 1$.

What happens to the driver costs if the number of passenger increase is observed in Figure 34. For $n=2$, the driver costs are even more economic in the CS model than in the non-fair Situation A for SWP model. For SFF and SWP in Situation A, the costs are a bit higher than before, but this increment is almost negligible because of the combustible consumption reasons. For the other models, as the driver shares the cost with the users, the bigger the number of users, the lower costs for the drivers.

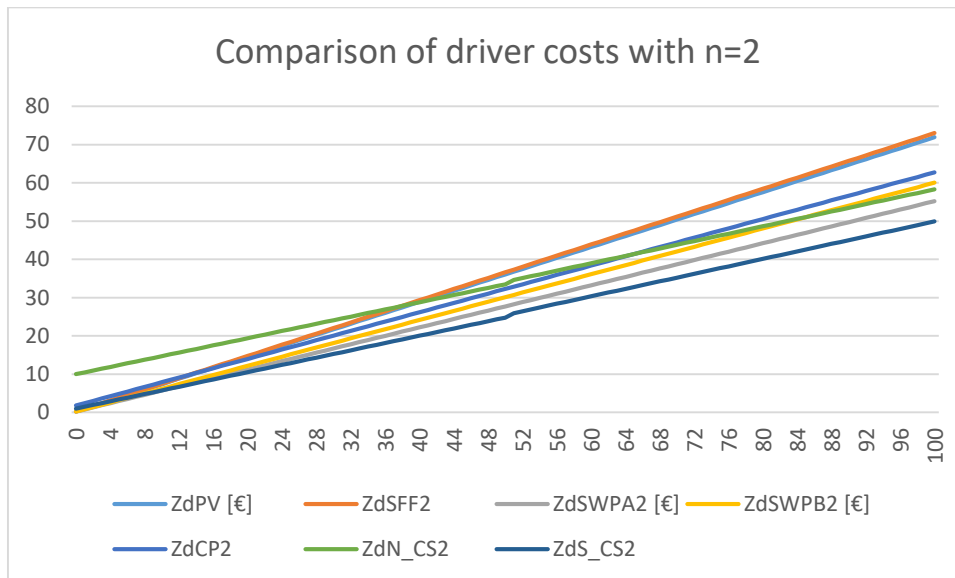


FIGURE 34. Comparison of the different driver costs depending on the model and \bar{d} , for $n = 2$.

6.7.2. ANALYSIS AND COMPARATION OF USER COSTS

This is an important result to allow the users now which models are most affordable for them.

In Figure 35 there is a comparison of user costs for all the modes, including Uber and Taxi, that are the most expensive ones due to the high fares. In the TC mode, the drivers are professionals, so the users pay more than in other modes because they have to produce some profit to the

drivers. The other observations are, that logically the SFF is the most economic one. Without taking it into account, when the payments to the driver and the sharing of costs is introduced, the most affordable solutions for users for long-trips are the ones related to carpooling: “traditional” carpooling, or SWP, and CP itself. For the users, CS is more expensive than CP when the trip length is long.

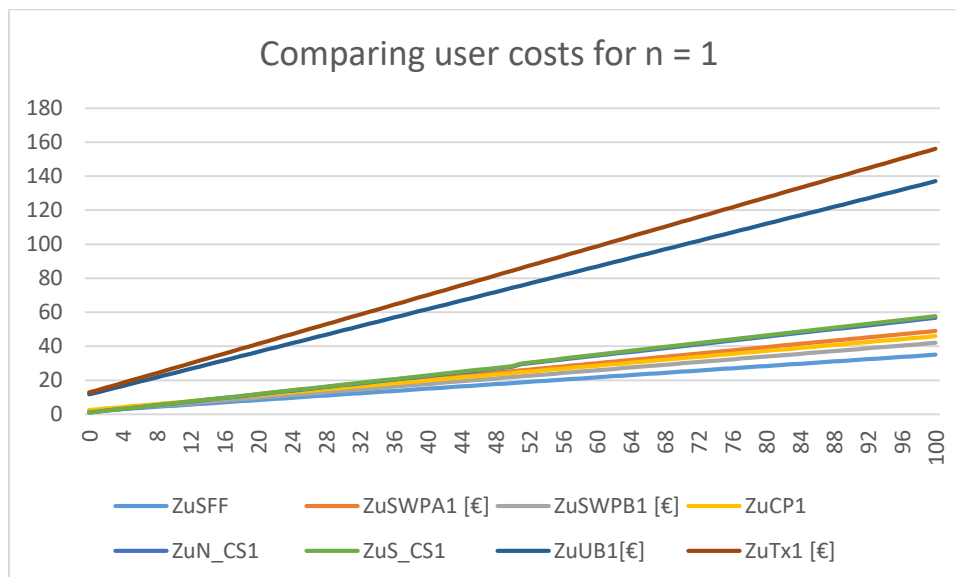


FIGURE 35. Comparison of the different user costs depending on the model and \bar{d} , for $n = 1$.

Also for the case of the users, it is a good tool to provide a grid with a grading of the costs, for commuting or urban trips no longer than 20 km. This is what Table 27 does. It is also useful to set a graphical comparison, as in Figure 36.

ZuSFF	ZuSWPA1	ZuSWPB1	ZuCP1	ZuNCS1	ZuSCS1	ZuUB1[€]	ZuTx1 [€]	d (km)
1.727	1.727	1.727	2.541	1.019	1.019	11.720	12.800	0
2.060	2.199	2.130	2.975	1.557	1.566	12.973	14.233	1
2.393	2.672	2.533	3.409	2.094	2.112	14.227	15.667	2
2.727	3.144	2.935	3.843	2.631	2.659	15.480	17.100	3
3.060	3.616	3.338	4.277	3.169	3.205	16.733	18.533	4
3.393	4.089	3.741	4.711	3.706	3.752	17.987	19.967	5
3.727	4.561	4.144	5.146	4.243	4.298	19.240	21.400	6
4.060	5.033	4.547	5.580	4.781	4.845	20.493	22.833	7
4.393	5.506	4.950	6.014	5.318	5.391	21.747	24.267	8
4.727	5.978	5.352	6.448	5.855	5.938	23.000	25.700	9
5.060	6.451	5.755	6.882	6.393	6.484	24.253	27.133	10
5.393	6.923	6.158	7.317	6.930	7.031	25.507	28.567	11
5.727	7.395	6.561	7.751	7.467	7.577	26.760	30.000	12
6.060	7.868	6.964	8.185	8.005	8.124	28.013	31.433	13
6.393	8.340	7.367	8.619	8.542	8.670	29.267	32.867	14
6.727	8.812	7.770	9.053	9.079	9.217	30.520	34.300	15
7.060	9.285	8.172	9.487	9.617	9.764	31.773	35.733	16
7.393	9.757	8.575	9.922	10.154	10.310	33.027	37.167	17
7.727	10.230	8.978	10.356	10.692	10.857	34.280	38.600	18
8.060	10.702	9.381	10.790	11.229	11.403	35.534	40.033	19
8.393	11.174	9.784	11.224	11.766	11.950	36.787	41.467	20

TABLE 27. Grading of the different user costs depending on the model and \bar{d} , for $n = 1$.

What it is observed in Figure 36 is one of the most important results. When there $n = 1$, so there are two persons into a vehicle, the most economic options for short-urban trips of less than 6 km are provided by CS services, independently of their condition as new or standard users. For long-urban trips, of more than 6 km, the SWP traditional ridesharing model is the most affordable for users. If it is considered only the modern ridesharing provided by companies, it is observed that CP models start to be more attractive than CS for $\bar{d} > 12 \text{ km}$, it is, short inter-urban trips, or typical commuter trips. It is then approved the idea of using CS for urban trips, into the city, and CP for commuting and long inter-urban trips. The costs of the TC model are not introduced in the figure because they are too much high, and in this way the figure is more accurate.

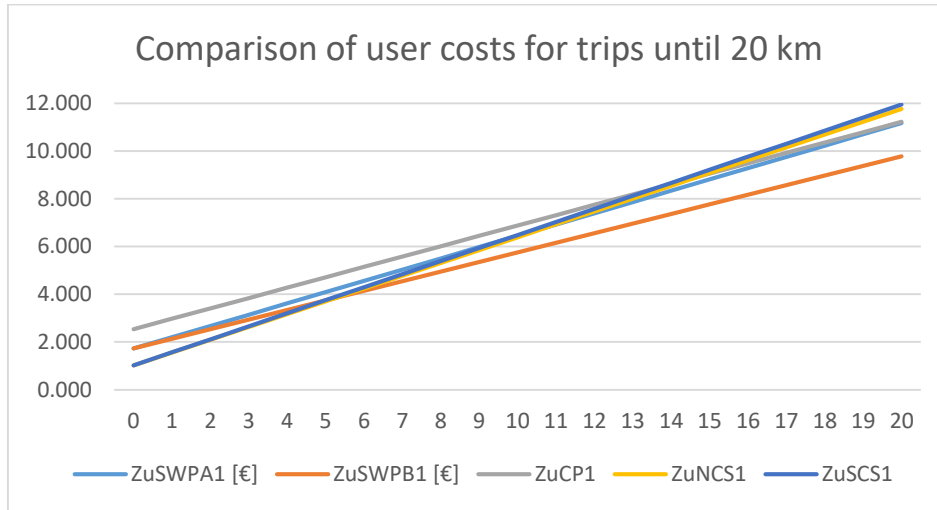


FIGURE 36. Comparison different user costs depending on the model and $\bar{d} \leq 20 \text{ km}$, for $n = 1$.

When more users are sharing the trip, the CS mode can be more attractive than CP for a long range of distance, up to 15 km at least, as observed in Figure 37. However, as explained above, it should be taken into account that in real life a special fees are applied when the vehicles of CS exceed the city region limits. Another observation that has also been made in the case of the drivers, is that also for the users the costs are reduced if the number of passengers is augmented, because of sharing effects.

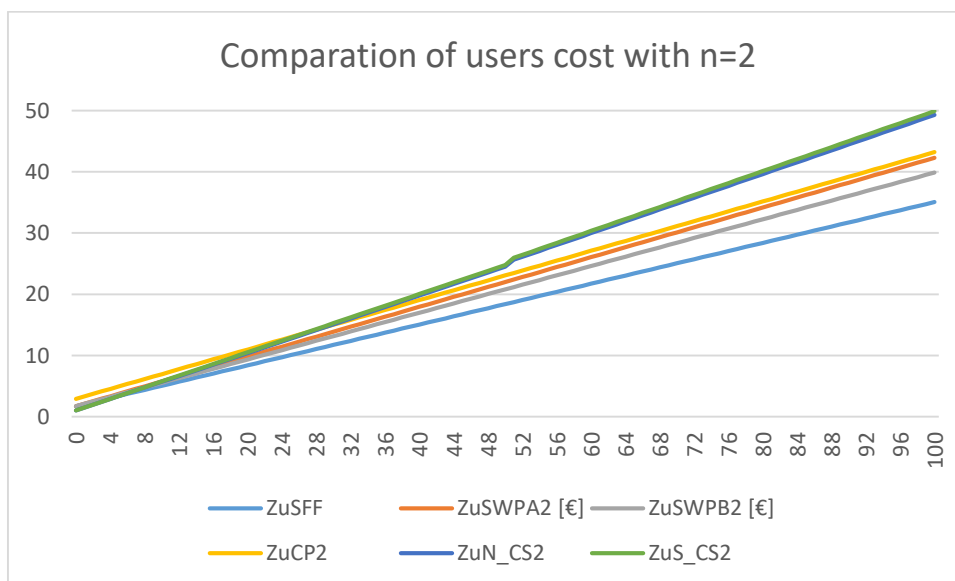


FIGURE 37. Comparison of the different user costs depending on the model and \bar{d} , for $n = 2$.

Another way of presenting the results in an easier and less technical manner is shown in Table 28. It represents the most economic options for the users depending on their trip length, up to 20 km, and the number of passengers from 1 to 3, and without taking into account SFF model. The advantage of this table is that, instead of giving directly the price, the Table shows the abbreviation of the model considered more attractive depending on the trip conditions. This would help to a wide range of users to understand the results, which is a helpful tool for enhancing ridesharing.

Even a classification with colors can be done, differencing between modern ridesharing, in green; or traditional ridesharing, in yellow. The green cells, or modern ridesharing, can achieve more environmentally friendly goals, and it is important to promote them. This Table is an example of presentation that can be also made for the costs of drivers and for higher trip distances or number of passengers.

Zu	d (km)	n [pax]		
		1	2	3
	0	CSs	CSs	CSs
	1	CSn	CSn	CSn
	2	CSn	CSn	CSn
	3	CSn	CSn	CSn
	4	SWP	CSn	CSn
	5	SWP	CSn	CSn
	6	SWP	CSn	CSn
	7	SWP	CSn	CSn
	8	SWP	CSn	CSn
	9	SWP	SWP	SWP
	10	SWP	SWP	SWP
	11	SWP	SWP	SWP
	12	SWP	SWP	SWP
	13	SWP	SWP	SWP
	14	SWP	SWP	SWP
	15	SWP	SWP	SWP
	16	SWP	SWP	SWP
	17	SWP	SWP	SWP
	18	SWP	SWP	SWP
	19	SWP	SWP	SWP
	20	SWP	SWP	SWP

TABLE 28. Best user solutions depending on \bar{d} , for $n = 1, 2$ and 3 .

The results obtained in Table 28, can contribute to some applications and companies to create an information platform for a wide range of public, if a real-data calibration was introduced. In this way, the users can observe whether the chance is not only the optimum in general (as what Table 28 shows), but if it is affordable in the present moment of the matching. It means that, if for example a Carsharing service is not available near to the initial location, it is not considered the best solution as it would be in an aggregated and continuous model.

Many of the results shown in this Chapter, can be also analyzed from one model to other. For short trip distances of less than 3 km, it can be considered that walking is affordable as a mode of transport. Further research can be done applying a modeling for the costs of walking and compare it with the presented costs of this study.

7. CONCLUSIONS AND FUTURE RESEARCH

7.1. CONCLUSIONS

The problems of commuting to the cities are related with the traffic congestion, the air pollution and the delays. To solve this situation, a chance is to use ridesharing services, but they should be promoted. In this study is presented a comparison of costs for drivers and users depending on their mode of transport and some conditions, helping to decide which is more convenient and enhancing ridesharing. The options that the ridesharing offer have more economic and beneficial solutions for each kind of trip. This could be used to shift some users to such a better way of mobility.

It has been useful to establish a grading of options between ridesharing modes. With this, it has been put on practice the taxonomy of a wide range of qualitative chances, taking into account their characteristics to make an ordination with sense. After this, it is easier to understand how the different modes work and how to study them. The decision and estimation of the variables used in the models is an example of meditation about which facts will affect considerably all the models, and how to evaluate them for the future application. It is not easy to simplify the parameters and attributes, and a carefully process of selection has been done. For estimating the variables, an important observation of databases should be carried out. It is such a relevant work to select and use this data in a proper way, with statistics and probabilistic procedures. Sometimes it was difficult to estimate some values or find some data related to them, so the study has assumed their values with tolerable reasons.

In order to compare the different modes, the study has developed a modeling of the ridesharing options. The formulation proposed in the models reflect some real life attitudes, which are simple to understand but difficult to study due to the variability and complexity of the data. The creation of the formulations is a complex technical work that should take into account important simplifications of real and physic phenomena's. Therefore, the formulations are valid if they comply with the hypotheses established. The modeling created uses similar variables. Thanks to that, applying specific conditions, in some cases the formulation of a model can be applied to other modes, as in the case for SFF and SWP when $n = 0$, that they conduce directly to the PV model formulation. Once the modeling is created, it has been analyzed varying different parameters, such as the trip distance and the fares, obtaining different costs for drivers and users. It is important to remark that the estimation of the variables has been focused on its application for commuters in the Metropolitan Area of Barcelona. This analysis helps to understand the behavior of the models into the region of study, calibrating them and observing if the hypotheses are achieved. The comparison of different costs for users and drivers is made between the models, from here the results are obtained in order to propose the different preferences for the solutions.

In this study it has been proved that ridesharing is such an economic way of moving. For those who do not travel too much, it is better not to own a vehicle and use other alternatives, ridesharing is one of them. Also for those who every day should travel, such as the commuters, sharing their trips is an optimum solution. One of the problems associated to the inhibition of ridesharing is the higher access and waiting times with respect to the private vehicle. It has been observed how much it affects to the costs, even more for short trips. This can be reduced with better matching services, and this can be achieved thanks to the technology innovations that are in our hands. In spite of this, some ridesharing modes are more economic for drivers than travelling with PV, this is the case, for example of CP for long-trips of more than 20 km. For the workers that commute, CP is a way of saving money, also as a passenger it is the best solution for inter-urban trips

between 12 and 20 km, because they pay less than the drivers do, but even more because it cost less than in other modes. In the case of CS the users pay the same as the driver, which is a user too. This is an important fact for attracting users and drivers to this mode. Their prices are not too much high, but more subventions and publicity could make them more affordable and attractive. However, for short-urban trips of less than 6 km, it is the typical best solution, even more than the traditional SWP. To conclude, the best way of reducing the costs in all the modes is to share them with a higher amount of users, this is ridesharing. It is important to consider that it is not only an economic, but also environmentally friendly mode of transport and it enhances the society benefits. A new mobility era is coming and the citizens should change the way of moving.

7.2. FUTURE RESEARCH

Due to complexity sakes, this study has adopted some simplifications that could be improved for simulating a real-life behavior of the models. The study has not taken into account how the congestion and the difference of velocities depending on the time of the day affected to the results. A better approach could be realized taking into account these facts, but considering that the level of congestion depends also on ridesharing usage, so it changes depending on ridesharing demand in a bi-lineal way, because ridesharing prices also depend on congestion. It has relation with the problem of the waiting time and the demand, explained many times along the study. Further research should be done to solve this problem, for example testing the models in many regions with different demand levels and behaviors, and calibrating the models to real-data to obtain results that are more realistic.

A point-to-point trip has been adopted in the study. This is such a simple way of modeling a trip route. However, in a real situation some deviations to get the passengers can be done. This can be further studied introducing how the extra distance influence the ridesharing prices. Furthermore, it is interesting to study the problem with an agent-based modeling, instead of an aggregated model. This, however, is more complex, taking into account OD matrixes. For a micro scale simulation, it would be useful.

It would be interesting to define and study different trip standards: students, workers, householders, leisure travelers and unemployed, for example. These trip standards are based on different VoT, different trip lengths, and even different trip routes. The proposed modeling can be adapted into a more complex one, extracting the preferences for modes, related to costs, and proposing MaaS packages depending on the trip standard, with the objective of promoting the use of ridesharing.

The society effects and costs were taken into account in a qualitative way, but they have not been modeled. Further research could be done on considering the society as a stakeholder, and calculating the pollution costs and the social welfare benefits. In spite of this, the model has considered some increments on prices approaches, that may reach the contribution for the environment costs, but this fact should be calibrated.

The new era of the mobility is introducing new concepts to the transport, such as the autonomous cars. Some research about how to compute its costs and how to introduce it into ridesharing services is of the interest for the science of transport.

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9. ANNEXES

ANNEX 1: VALUES USED FOR THE ESTIMATION OF FARES IN CS AND TC MODELS.

Prices in detail	
Valid till 13th Sept.	
Validation fee	9,00 €***
Drive or park per minute	0,21 €
24 hours driving (per car)	59,00 €
In addition each kilometer after 50km	0,29 €
Administrative management fee fine	20,00 €
Processing of towing operations	50,00 €
Administrative fee for a fine or penalty	50,00 €
Administrative processing fee charged for unpaid bills	10,00 €
Administrative fee penalty for special case	150,00 €

TABLE 29. Prices for fees and rates for Car2Go. [<https://www.car2go.com/ES/en/madrid/costs/>]

tarifas de conducción para barcelona

Las tarifas de conducción de Avancar cambian dependiendo de la zona donde conduces, el tipo de coche o la duración de tu reserva. En Barcelona, nuestras tarifas más bajas empiezan en 1,50€/hora y 30€/día. Y cuando necesites tu Avancar para más de un día, puedes aprovechar nuestras tarifas especiales Multidía.

tarifas horarias y diarias

Tarifas Multidia

plan star

plan smart

plan light

tipos de vehículos	Semana		Fin de semana		Km Extra	Km Incl.
	Hora	Dia	Hora	Dia		
<div> <div>0 km</div>  <div>Hyundai i10</div> </div> <div> <div>0 km</div>  <div>Toyota Yaris Hybrid City</div> </div>	5 €	60 €	6 €	70 €	0,25 €	0 km
<div> <div>0 km</div>  <div>Hyundai Ioniq Hybrid City Plus</div> </div>	6 €	65 €	7 €	75 €	0,25 €	0 km

TABLE 30. Prices for fees and rates for Avancar. [<http://www.avancar.es/check-rates/Barcelona>]

	Blue Bienvenida SIN CUOTA		Blue con cuota DESDE 5€ AL MES		Blue sin cuota SIN CUOTA	
	Hora	Día	Hora	Día	Hora	Día
Economy	2,50€	29,00€	2,50€	29,00€	4,00€	42,00€
Cool	2,90€	35,00€	3,20€	34,00€	4,50€	47,00€
Comfort	3,50€	39,00€	3,70€	39,00€	5,00€	52,00€
Cargo	5,30€	49,00€	5,80€	49,00€	7,20€	60,00€
Coche eléctrico ¹	4,00€	45,00€	4,00€	45,00€	6,20€	45,00€
0,29€/km los primeros 100km (0,25€/km categoría Economy con Blue Bienvenida) 0,18€/km desde el km 100						
¹ Los vehículos eléctricos no tienen coste de km.						

TABLE 31. Prices for fees and rates for Bluemove [<https://bluemove.es/es/precios>]

Spain - Ranking by Sample Fares					
Nombre de la ciudad	Cargo inicial	Cargo por millas	Tarifa corta típica	Tarifa media típica	Tarifa larga típica
1. Malaga, Spain	3,48 €	1,42 €	6,46 €	17,22 €	30,18 €
2. Barcelona, Spain	2,10 €	1,03 €	5,52 €	16,23 €	28,41 €
3. Valencia, Spain	4,00 €	1,13 €	5,12 €	14,27 €	25,85 €
4. Madrid, Spain	2,10 €	1,06 €	3,90 €	13,38 €	24,46 €
5. Palma de Majorca, Spain	3,00 €	0,85 €	4,01 €	10,98 €	19,24 €
6. Seville, Spain	2,66 €	0,66 €	4,49 €	10,51 €	17,52 €
7. Zaragoza, Spain	2,70 €	0,75 €	3,67 €	10,37 €	18,19 €

TABLE 32. Sample fares for Uber in different cities of Spain. [TaxiFareFinder: Tabla de clasificación de tarifas de taxi en los Estados Unidos: tarifas de muestra, <https://www.taxifarefinder.com/rates.php>]

Concepte	Euros
Baixada de bandera T-1	2,10
Km recorregut T-1	1,10
Percepció mínima trajectes	7

TABLE 33. Barcelona taxi fares for T-1 trips. [Adapted from Tarifes – Taxi, <http://taxi.amb.cat/s/taxista/tarifes-i-taxes.html>]

ANNEX 2: ANALYSIS AND RESULTS OF THE APPLICATION OF THE MODELING OBTAINED WITH EXCEL.

d (km)	ZdPV [€]	ZdN_CS0 [€]	ZdS_CS0 [€]
0	0.22	10.02	1.02
1	0.91	10.76	1.78
2	1.60	11.50	2.54
3	2.28	12.24	3.30
4	2.97	12.98	4.06
5	3.66	13.73	4.82
6	4.34	14.47	5.58
7	5.03	15.21	6.34
8	5.72	15.95	7.10
9	6.40	16.69	7.86
10	7.09	17.43	8.62
11	7.78	18.17	9.38
12	8.46	18.92	10.14
13	9.15	19.66	10.90
14	9.83	20.40	11.65
15	10.52	21.14	12.41
16	11.21	21.88	13.17
17	11.89	22.62	13.93
18	12.58	23.36	14.69
19	13.27	24.11	15.45
20	13.95	24.85	16.21

TABLE 34. Results of Z_{dpv} for the first 20 km.

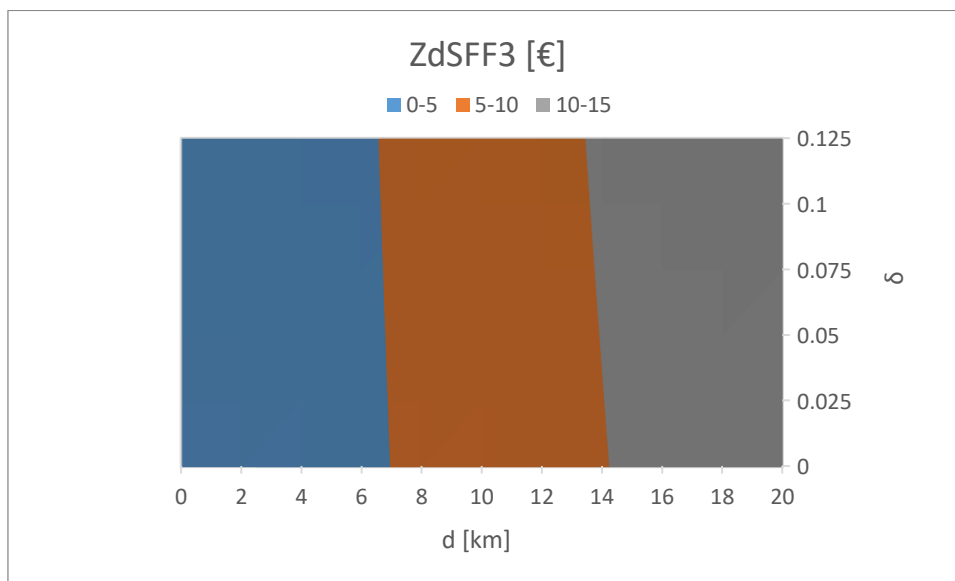


FIGURE 38. Analysis of driver costs with δ and \bar{d} in SFF model with $n = 3$.

d [km]	ZuSWPB1 [€]	ZuSWPA2 [€]
0	1.726809524	1.726809524
1	2.131135038	2.133845826
2	2.535460553	2.540882128
3	2.939786067	2.94791843
4	3.344111582	3.354954732
5	3.748437096	3.761991034
6	4.152762611	4.169027336
7	4.557088125	4.576063638
8	4.96141364	4.98309994
9	5.365739154	5.390136242
10	5.770064669	5.797172544
11	6.174390183	6.204208846
12	6.578715698	6.611245148
13	6.983041212	7.01828145
14	7.387366727	7.425317752
15	7.791692241	7.832354054
16	8.196017756	8.239390356
17	8.60034327	8.646426658
18	9.004668785	9.05346296
19	9.408994299	9.460499262
20	9.813319814	9.867535564
21	10.21764533	10.27457187
22	10.62197084	10.68160817
23	11.02629636	11.08864447
24	11.43062187	11.49568077

25	11.83494739	11.90271707
26	12.2392729	12.30975338
27	12.64359842	12.71678968
28	13.04792393	13.12382598
29	13.45224944	13.53086228
30	13.85657496	13.93789858
31	14.26090047	14.34493489
32	14.66522599	14.75197119
33	15.0695515	15.15900749
34	15.47387702	15.56604379
35	15.87820253	15.97308009
36	16.28252805	16.3801164
37	16.68685356	16.7871527
38	17.09117907	17.194189
39	17.49550459	17.6012253
40	17.8998301	18.0082616
41	18.30415562	18.41529791
42	18.70848113	18.82233421
43	19.11280665	19.22937051
44	19.51713216	19.63640681
45	19.92145768	20.04344311
46	20.32578319	20.45047942
47	20.73010871	20.85751572
48	21.13443422	21.26455202
49	21.53875973	21.67158832
50	21.94308525	22.07862462
51	22.34741076	22.48566093
52	22.75173628	22.89269723

53	23.15606179	23.29973353
54	23.56038731	23.70676983
55	23.96471282	24.11380613
56	24.36903834	24.52084244
57	24.77336385	24.92787874
58	25.17768936	25.33491504
59	25.58201488	25.74195134
60	25.98634039	26.14898764
61	26.39066591	26.55602395
62	26.79499142	26.96306025
63	27.19931694	27.37009655
64	27.60364245	27.77713285
65	28.00796797	28.18416915
66	28.41229348	28.59120546
67	28.816619	28.99824176
68	29.22094451	29.40527806
69	29.62527002	29.81231436
70	30.02959554	30.21935066
71	30.43392105	30.62638697
72	30.83824657	31.03342327
73	31.24257208	31.44045957
74	31.6468976	31.84749587
75	32.05122311	32.25453217
76	32.45554863	32.66156848
77	32.85987414	33.06860478
78	33.26419965	33.47564108
79	33.66852517	33.88267738
80	34.07285068	34.28971368

81	34.4771762	34.69674999
82	34.88150171	35.10378629
83	35.28582723	35.51082259
84	35.69015274	35.91785889
85	36.09447826	36.32489519
86	36.49880377	36.7319315
87	36.90312928	37.1389678
88	37.3074548	37.5460041
89	37.71178031	37.9530404
90	38.11610583	38.3600767
91	38.52043134	38.76711301
92	38.92475686	39.17414931
93	39.32908237	39.58118561
94	39.73340789	39.98822191
95	40.1377334	40.39525821
96	40.54205892	40.80229452
97	40.94638443	41.20933082
98	41.35070994	41.61636712
99	41.75503546	42.02340342
100	42.15936097	42.43043972

TABLE 35. *Comparison between ZuSWPB1 and ZuSWPA2.*

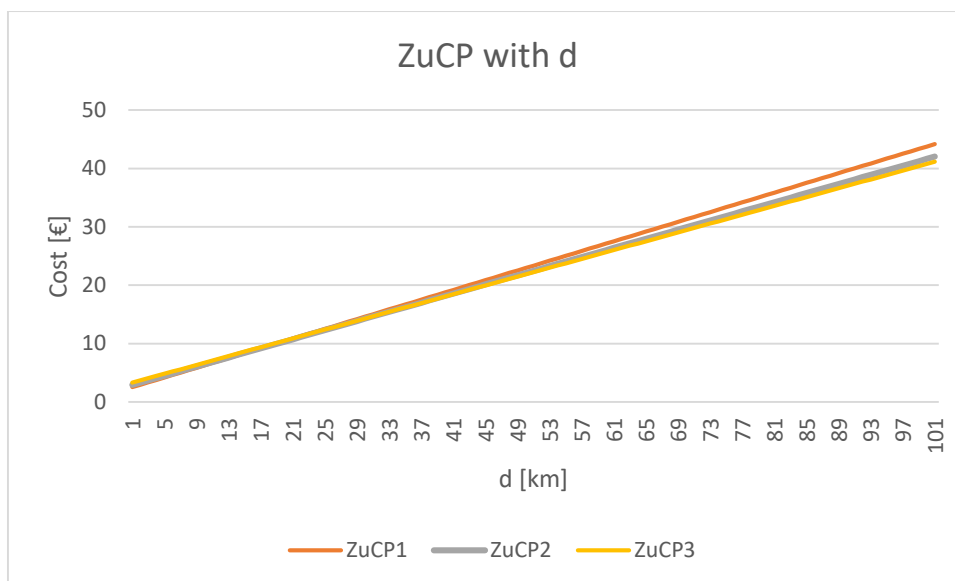


FIGURE 39. User costs in CP model with \bar{d} , for $n = 1, 2$ and 3 .

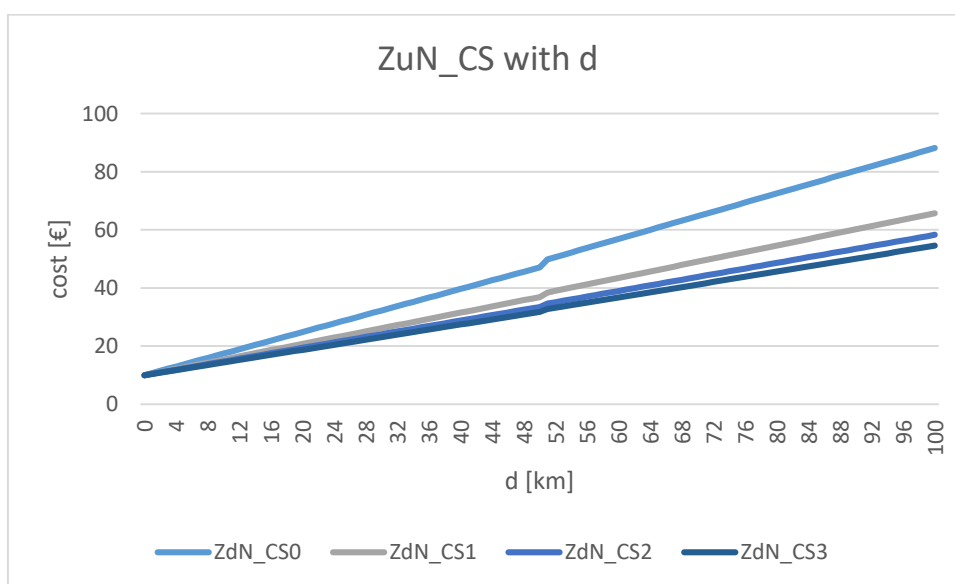


FIGURE 40. New driver costs in CS model with \bar{d} , for $n = 0, 1, 2$ and 3 .

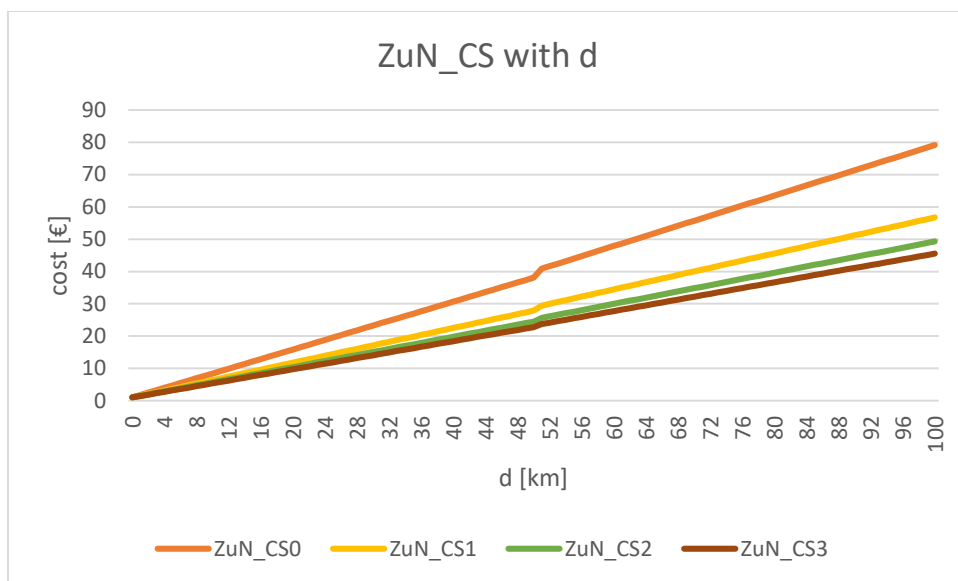


FIGURE 41 New user costs in CS model with \bar{d} , for $n = 0, 1, 2$ and 3 .

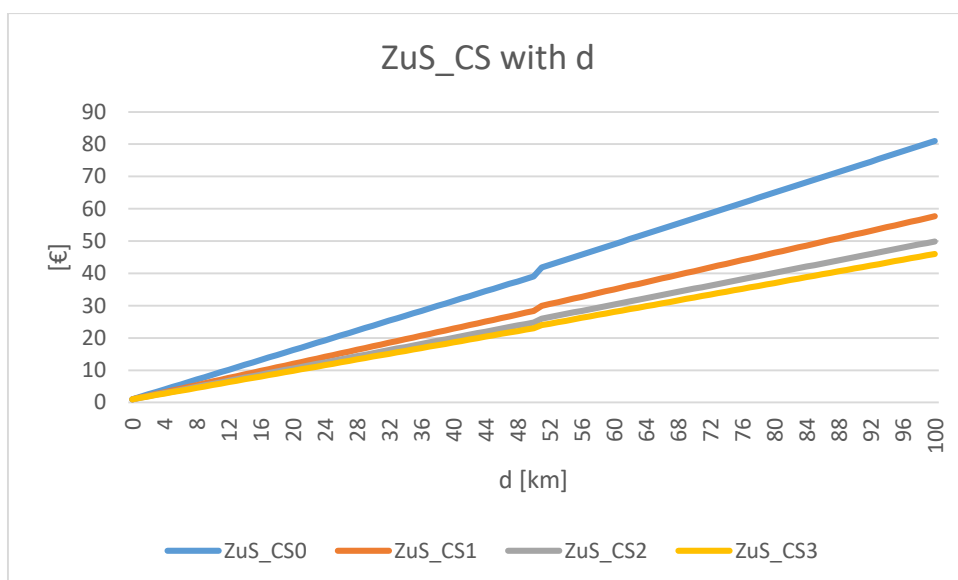


FIGURE 42. Standard user costs in CS model with \bar{d} , for $n = 0, 1, 2$ and 3 .

ZuS1 [€]	Gh [€/h]								
4.29837659	0	2	4	6	8	10	12	14	
Gkm [€/km]	0	3.043	3.243	3.443	3.643	3.843	4.043	4.243	4.443
	0.05	3.193	3.393	3.593	3.793	3.993	4.193	4.393	4.593

0.1	3.343	3.543	3.743	3.943	4.143	4.343	4.543	4.743
0.15	3.493	3.693	3.893	4.093	4.293	4.493	4.693	4.893
0.2	3.643	3.843	4.043	4.243	4.443	4.643	4.843	5.043
0.25	3.793	3.993	4.193	4.393	4.593	4.793	4.993	5.193
0.3	3.943	4.143	4.343	4.543	4.743	4.943	5.143	5.343

TABLE 36. Analysis of driver or user costs in Standard situation for CS model, with G_h and G_{km} for $\bar{d} = 6 \text{ km}$ and $n = 1$.

ZuS2 [€]	Gh [€/h]								
3.87201825	0	2	4	6	8	10	12	14	
Gkm [€/km]	0								
0	3.035	3.169	3.302	3.435	3.569	3.702	3.835	3.969	
0.05	3.135	3.269	3.402	3.535	3.669	3.802	3.935	4.069	
0.1	3.235	3.369	3.502	3.635	3.769	3.902	4.035	4.169	
0.15	3.335	3.469	3.602	3.735	3.869	4.002	4.135	4.269	
0.2	3.435	3.569	3.702	3.835	3.969	4.102	4.235	4.369	
0.25	3.535	3.669	3.802	3.935	4.069	4.202	4.335	4.469	
0.3	3.635	3.769	3.902	4.035	4.169	4.302	4.435	4.569	

TABLE 37. Analysis of driver or user costs in Standard situation for CS model, with G_h and G_{km} for $\bar{d} = 6 \text{ km}$ and $n = 2$.

ZdUB [€]		Gkm [€/km]						
		0	0.25	0.5	0.75	1	1.25	1.5
n [pax]	1	5.341	4.491	0.741	-3.009	-6.759	-10.509	-14.259
	2	5.422	4.572	0.822	-2.928	-6.678	-10.428	-14.178
	3	5.504	4.654	0.904	-2.846	-6.596	-10.346	-14.096
ZdTX [€]		Gkm [€/km]						
		0	0.25	0.5	0.75	1	1.25	1.5
n [pax]	1	5.572	5.572	2.972	-0.778	-4.528	-8.278	-12.028
	2	5.653	5.653	3.053	-0.697	-4.447	-8.197	-11.947
	3	5.734	5.734	3.134	-0.616	-4.366	-8.116	-11.866

TABLE 38. Analysis of costs for Uber and Taxi drivers in TC model, with n and G_{km} for $\bar{d} = 15km$.

Gkm = 0.92 d = 15 km	
n	ZdUB
1	-5.5591
2	-5.4778
3	-5.3965

TABLE 39. Driver costs for Uber drivers in TC model, with different n , for $G_{km} = 0.92€/km$ and $\bar{d} = 15 km$.